INVESTIGATION OF THE PRINCIPLES OF RAPID SOIL TESTS FOR AVAILABLE POTASH AND OTHER PLANT NUTRIENTS OF VIRGINIA SOILS: III. SELECTION, DEVELOPMENT AND CALIBRATION OF RAPID CHEMICAL SOIL TESTS FOR AVAILABLE POTASSIUM, PHOSPHORUS, CALCIUM AND MAGNESIUM

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INTRODUCTION

Since Sir Humphrey Davy's day agricultural investigators have dreamed of a quick chemical test that could be used as a practical basis for determining the fertilizer needs of the soil. During the century or more since his time chemistry has been applied with diligence to the many problems of crop and soil relationships. Great masses of data have been accumulated, and much has been learned about the nutritional requirements of crops and about the many factors that influence the efficiency of crop growth.

It was quickly discovered that total chemical analysis bore little or no relationship to the ability of the soil to provide nutrient elements to the crop. Total chemical analysis did provide information which was used as a partial basis for understanding the genesis of important soil groups and their chemical properties.

By the establishment of experimental fields on representative soil types, it was possible to arrive at general principles governing the fertilizer requirements of different soils and crops. However, as cropping systems and fertilizer practice became established in older areas, it became evident that crop removals or fertilizer additions over a period of years can drastically shift the chemical balance in the soil on any given field. It became necessary to accept the fact that a soil type is not a chemical entity, nor can a knowledge of its inherent properties be used as the sole guide to the fertilizer requirements of a definite field (14, 50).

Recurring interest has been shown in "selective" solvents which will simulate the seasonal feeding capacity of crops, or at least measure that portion of the soil supply of the various nutrients which is most significant to crop growth. A number of so-called "quick tests" based on fractional solution and micro-chemical determination of the various soil nutrients have been developed and are being used in different areas (2, 9, 27, 39, 47, 48).

The essential difference between the various rapid soil test procedures is in the solvent, or extracting solution which is used. The measurement of the amount of each element extracted is based on more or less rigid chemical methods. In most cases these tests have been interpreted on a high-low-medium basis, to distinguish between soils where no response to additions of the nutrient might be expected and those where additions might be expected to give increased yields.

A few workers in certain areas have used the "balance-sheet" concept with very good success. Soil supplies as indicated by soil test are related quantitatively to the estimated needs of each individual crop (28, 42).

More recently an attempt has been made in this country to interpret soil test results in the light of Mitscherlich's"law of action of the growth factors." (11, 13). This formula attempts to define the hyperbolic nature of plant response to increasing increments of the positive growth factors. After calibration with a given extractant on a given soil and with a given form of the nutrient, the formula permits fertilizer recommendations to be made, which are related quantitatively to the soil test.

From the standpoint of economy to the farmer and efficiency in the utilization of national resources, it is important that fertilizer usage be closely hinged upon crop needs. A soil test interpreted on a high-low-medium basis does not furnish the information necessary to limit fertilizer applications to the amounts actually required by the crops to be grown. As higher and higher rates of fertilization comes into use, it becomes ever more necessary to relate fertilizer applications more or less quantitatively to soil supplies and crop needs. Where it can be applied, the balance sheet interpretation is satisfactory for this purpose.

The balance sheet interpretation presupposes an extracting solution which can remove in a few minutes' exposure to the soil a fraction of soil nutrients very closely equivalent to the fraction removed during the growing season by the particular crops with which the testing procedure is to be used. Obviously, if such an extractant is found, its area of application is likely to be limited to a few soils and crops. Different levels of free carbonates, for example, will change the effective pH of the extractant to different degrees. Variations in base exchange capacity can affect the equilibrium established between soils and extractant. The supplies of nutrients in the subsoil will be a qualifying factor with some crops.

The quick test extracting solutions differ in pH and composition from the root acids. Any equivalences, - if and when it occurs, - between extracting power of the solution and "feeding power" of any particular crop must be empirical. It cannot be expected to hold true for many soils nor all crops. At best, arbitrary correction factors must be applied to soil test values to calibrate them to different crops and different soils. When the correction factors have been determined for each crop and soil or group of soils, the balance sheet concept still assumes a straight line relationship between soil supplies and crop yield and between fertilizer additions and crop response. Almost any group of experimental data covering ratio or rate applications of fertilizer reveals that the response to increasing increments of the various nutrients represents a curve rather than a straight line.

Bray's adaptation of Mitscherlich's principle (11, 12, 13) attempts to define this response curve. It does so in terms that permit conversion of soil test values into fertilizer recommendations graduated according to crop need. It allows for differences between soils, crops and different forms of each nutrient by requiring a separate calibration of a given extractant for each crop on each of distinctly different groups of soils and for each form of the nutrient which is commonly used in fertilizers. For these reasons, this concept would appear to provide a means for improving the accuracy of fertilizer recommendations based on rapid chemical soil tests.

In recent years, plant tissue testing has come into use (17, 48). Its value as a tool in the practical diagnosis of nutrient needs and as an adjunct to soil fertility research investigations has been clearly shown. (18, 19).

OBJECTIVES

The soil testing system used by the Virginia Agricultural Extension Service was developed originally for Coastal Plains Soils (26). Its applicability to the soils of the Piedmont and Mountain provinces has been seriously questioned.

In 1939 a project sponsored by the American Potash Institute was set up to study the principles involved in selecting and calibrating a rapid soil test for the widely variant soils and crops in Virginia. The investigation was begun by C. S. Brandt, who reported on the first year's work in a thesis submitted in 1940 (5). E. J. Barber carried on the study in its second year, and reported his findings in 1941 (1).

The experimental work reported in this paper was conducted during the period June 1941 to June 1942. It is a continuation of Brandt's and Barber's work and was sponsored by the same organization.

Specifically the work was undertaken in pursuance of the following objectives:

1. To select an extracting solution capable of removing significant fractions of the major crop nutrients from several important agricultural soils in Virginia, that vary widely chemically and physically.

2. To establish rapid chemical testing procedures, with particular attention to simplified reading methods. Greater accuracy over a wider range than is true of many of the simplified reading techniques described in the literature is desirable if a balance sheet or growth curve interpretation is to be made.

3. To calibrate soil test results against crop responses to fertilization and establish a scheme for interpreting soil tests in terms of fertilizer recommendations.

4. To evaluate in a preliminary manner the use of plant tissue testing under Virginia conditions as a diagnostic technique in conjunction with soil testing.

PART I

LABORATORY MATERIALS AND METHODS

A. PREPARATION OF SOIL SAMPLES

The soil samples used in this study were collected in the fall of 1940 and the spring of 1941. A few were taken in the spring of 1942. Each sample was composited from several locations over the area represented. The samples were air-dried soon after taking from the field. They were then screened through a 2 mm sieve to remove inert and non-representative coarse materials. Samples were mixed by hand-shaking and stored in waxed ice-cream cartons.

B. SOIL ACIDITY

Determinations of soil acidity were made with the Beckman pH-meter, using a glass electrode. Soil samples for pH determination were saturated to excess with freshly distilled water and allowed to stand overnight before readings were taken.

C. ORGANIC MATTER

Organic matter was determined in connection with only two experiments. The chromic acid digestion procedure as outlined by Peach and Dean was used (40).

D. EXTRACTANTS AND ABSORPTION SOLUTIONS

The extracting solutions that are being used by soil testing laboratories in different areas vary greatly in concentration, buffer capacity and in the activity of the displacing ions. Following Barber's example (1), an attempt was made in this study to compare extractants which differ widely in the above properties.

The extractants and absorption solutions which were used are given below:

* Bray's Sodium Perchlorate (9) as modified by Barber (1) was prepared by dissolving 220 gms of $NaClO_4 \cdot H_2O$ in 780 cc of ammonia-free water and adding 1 cc of 70% $HClO_4$. (This solution was not used to extract phosphorus because of technical difficulties in getting a suitable color reaction.)

* Morgan's Universal Extracting Solution (39), was prepared as follows: Dissolve 100 gms of sodium acetate in 500 cc of distilled water, add 30 cc of glacial acetic acid and make up to one liter with distilled water. It has a pH of about 4.8.

Hester's Extractant, first modification is referred to in this report as "Hester I." It was prepared as follows: Dissolve 40 gms of sodium acetate in 500 cc of distilled water, add 40 cc of glacial acetic acid and make up to one liter with distilled water. This modification of the solution described by Hester (27) was used for a time by the Virginia Agricultural Extension Service. It has a pH of approximately 4.2 and was selected for this study because it is intermediate in buffering between

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* Note: These extracting solutions were also used by Barber in the preceding phaze of this investigation (1).

Morgan's Universal Extractant and the second modification of the Hester solution.

*Hester's Extractant, second modification is here referred to as "Hester II." It was prepared by dissolving 25 gms of sodium acetate in 500 cc of distilled water. To this was added 40 cc of glacial acetic acid and the solution made up to one liter with distilled water. This is the extracting solution used at the present time by the Virginia Agricultural Extension Service. It has a pH of about 4.0. (The original solution described by Hester (27) was buffered to a pH of 5.0).

Thornton's Potassium Extractant (48) was made up in stock solution as follows: 5 gms of sodium cobaltinitrite and 30 gms of sodium nitrite are dissolved in distilled water; add 5 cc of glacial acetic acid, make up to 100 cc and allow to stand unstoppered for several days; filter and store in a refrigerator. Daily, or at the time of use, 5 cc of the stock solution are added to a solution of 15 gms of sodium nitrite in 100 cc of distilled water. This diluted solution is the one that was actually used in the potassium extraction. It was adjusted to pH 5.0 with acetic acid before using.

Thornton's Phosphorus Extractant (48) as modified by Ruhnke, et al (43), was prepared by diluting 4 cc of concentrated H Cl to one liter with distilled water. This gave a solution .05N with respect to H Cl, with a pH of 1.4.

Purvis Absorption Solution (41). As proposed by Purvis, this was an aqueous solution containing 4.58 ppm P_2O_5 and 241 ppm K_2O. In the present investigation, two modifications were used to give concentrations adapted to the varying ranges of fixing capacity encountered in the soils which were studied. Five-hundred cc of 95% ethyl alcohol were added per liter of testing solution to eliminate cloudiness in the extracts. Stock solutions and testing solutions were prepared as follows:

Purvis Stock Solution A: (160 ppm P_2O_5 plus 212 ppm K_2O, as K_2HPO_4). Make up 0.392 gms K_2HPO_4 to 1 liter with distilled water.

Purvis Stock Solution B: (788 ppm K_2O, as K Cl). Make up 1.248 gms K Cl to 1 liter with distilled water.

Purvis Test Solution I: (16 ppm P_2O_5 plus 100 ppm K_2O). Combine 100 cc each of Stock Solution A and B. Add 500 cc of 95% ethyl alcohol and make up to 1 liter with distilled water.

Purvis Test Solution II: (32 ppm P_2O_5 plus 200 ppm K_2O, - for silt loams, clay loams, and clays). Combine 200 cc each of Stock Solutions A and B. Add 500 cc of 95% ethyl alcohol and make up to 1 liter with distilled water.

E. EXTRACTING PROCEDURES AND CONVERSION FACTORS

1. Methods of extraction used for K_2O, CaO, and MgO:

For K_2O, CaO and MgO the same soil-to-solution ratio and the same extraction time was used with each extracting solution (and the Purvis absorption solution) as was described in the original literature. These ratios and times are tabulated in Table 1. Also listed in Table 1 are the factors used in each case to convert ppm in the test results to pounds per acre.

For the extractions calling for a 1:1.5 soil-to-solution ratio a special measure was made. The volume of this measure was 10.9 cc, which was found to approximate 13.3 grams of soil. The proportion of 1:1.5 (weight basis) was achieved by extracting the 13.3 gram measure of soil with 20 cc of the solution. In the case of the 1:2 ratios a 4.1 cc measure, holding about 5 grams of soil, was extracted with 10 cc of the solution.

Extractions were carried out in 100 cc erlenmeyer flasks. Soil samples and solutions in the erlenmeyer flasks were shaken vigorously three times during the extraction period, regardless of the length of the specified period.

After extraction, the solutions were filtered to give clear solutions for testing. With some soils repeated filtering was necessary, in which case solutions were passed back through the same filter.

2. Methods of extraction used for P_2O_5:

A 1:2 soil-to-solution ratio (weight basis) was used with the Purvis absorption solution. The soil-to-solution ratio for all extractants used for phosphorus was standardized at 1:4 (by weight). To achieve the 1:4 ratio, a 5 gram measure of soil was extracted with 20 cc of solution.

As with K_2O, CaO and MgO, the soil samples and solutions were shaken vigorously in erlenmeyer flasks three times during the extraction. Filtering procedures were the same. The extraction ratios, times of extraction, and conversion factors used for P_2O_5 are shown in Table 2.

Table 1: Ratio by weight of soil to solution, time of extraction and conversion factors for the extraction methods used with K_2O, CaO and MgO.

Extraction Method	Ratio of soil to solution	Time of extraction	Factor x ppm to give lbs. per acre
Bray	1:2	2 min.	4
Thornton	1:2	2 "	4
Morgan	1:2	2 "	4
Hester I	1:1.5	20 "	3
Hester II	1:1.5	20 "	3
Purvis (absorption)	1:2	30 "	*

* For the Purvis absorption solution, parts per million before absorption minus parts per million after absorption x 4 = pounds per acre absorbed by the soil.

Table 2: Ratio by weight of soil to solution, time of extraction and conversion factors for the extraction methods used for P_2O_5.

Extraction Method	Ratio of soil to solution	Time of extraction	Factor x ppm to give lbs. per acre
Thornton	1:4	2 min.	8
Morgan	1:4	2 "	8
Hester I	1:4	20 "	8
Hester II	1:4	20 "	8
Purvis (absorption)	1:2	30 "	*

* For the Purvis absorption solution parts per million before absorption minus parts per million after absorption x 4 = pounds per acre absorbed by the soil.

F. TESTING REAGENTS AND PROCEDURES

In the interest of saving time and materials, testing reagents and procedures were standardized insofar as possible without changing the essential and specific nature of the extracting solution or the sensitivity of the tests as described in the original literature.

In the case of Thornton's potassium extractant, it was felt that the essential nature of the extracting solution, as well as the sensitivity of the test, might be altered by leaving the cobaltinitrite out of the extractant. The procedure as described by Thornton (43) was followed, with the exception of the addition of formaldehyde to eliminate interference by the ammonium ion.

The wide range of acidity and buffer capacity represented by the extractants made it necessary to vary the normality of H Cl in the molybdate reagent. Otherwise, the reagent as described by Thornton (43), was used with all extractants.

The standardized procedures which were used for calcium and magnesium were the result of combining refinements described in several procedures.

The reagents and procedures that were used in this study are described below:

1. Potassium

a) Potassium reagents

1) Sodium cobaltinitrite stock solution is identical to the stock solution used in making up Thornton's potassium extractant (p. 13).

2) Sodium cobaltinitrite test solution is prepared by making 5 cc of the stock solution up to 100 cc with distilled water.

3) 40% formaldehyde, used to eliminate interference by the ammonium ion (1, 9).

4) Anhydrous iso-propyl alcohol, used as a sensitizer with Thornton's potassium extractant.

5) 95% ethyl alcohol, used as a sensitizer with all extractants except Thornton's.

b) Potassium procedures

1) Purvis absorption method:

To 4 cc of extract in a flat-bottomed vial add 1 cc of a mixture of equal parts of 40% formaldehyde and sodium cobaltinitrite test solution. Mix with an easy rotary motion and read after 3 minutes (see reading method, below). The absorption solution is made up with 500 cc per liter of 95% ethyl alcohol. No additional alcohol is required as a sensitizer.

2) Thornton's potassium method:

As quickly after filtration as possible, 3 cc of extract are added to 0.5 cc of 40% formaldehyde in a flat-bottomed vial. These are mixed thoroughly, and immediately 1.5 cc of anhydrous iso-propyl alcohol is added carefully down the side of the vial so that extract and alcohol form separate layers. These are mixed with an easy rotary motion, and readings are made after 3 minutes.

3) Other methods:

To 2 cc of extract in a vial is added 1 cc of a mixture of equal parts of 40% formaldehyde and sodium cobaltinitrite test solution. These are mixed thoroughly, and immediately 2 cc of 95% ethyl alcohol are added carefully down the side of the vial so that extract and alcohol form separate layers. These are mixed with an easy rotary motion, and readings are made after 3 minutes.

4) General notes on potassium procedures:

The mixture of equal parts of 40% formaldehyde and sodium cobaltinitrite test solution should be made at the time of use. It should not be allowed to stand.

Tests should be developed within the temperature range of 18 degrees to 25 degrees C. (9). To accomplish this, all reagents were kept in the refrigerator. Also test vials were immersed in a pan of tap water (18 degrees C) during the three minutes prior to reading.

In all potassium procedures it is important that tests be developed in the shortest time interval possible after addition of the cobaltinitrite. In extracts containing high concentrations of potassium, precipitation may start before addition of the alcohol. The precipitate formed in aqueous solution is coarser grained than that formed in an alcoholic medium and gives lower readings.

c) Reading method for potassium:

In this study, readings were made against a background of graduated black and yellow lines as described by Hester (27). The background was mounted over a 15 watt light bulb in a box of the nature of a dark-room light. A box-like shield was fitted to slide over the background of lines. Holes in the shield permitted insertion of the test vials in such a manner that the black and yellow lines could be viewed through the test solution without interference from reflections from external light sources (1, 9).

Readings over the higher range of concentrations were made by looking through the cross-section of the column of test solution. Readings over the lower range of concentrations were made by looking down through the height of the column.

The volumes of extract and reagents were modified to give a final volume of 5 cc. In a vial 14 mm in diameter, this gave a height of column of 24 mm. Thus a greater sensitivity in readings was secured in the lower ranges of concentration by viewing the black and yellow lines through a greater thickness of suspension. A mere mechanical manipulation of the vial reduced the thickness of suspension and extended the upper range of readings without the necessity for making new tests on diluted samples of extract.

The use of the light and the elimination of reflections through use of the movable shield also extended the upper range of readings.

The black and yellow lines were calibrated and checked regularly against standards of known concentrations. Separate series of standards were made up in each extracting solution. It was found that the calibration was similar for all extractants except Thornton's, and Purvis' absorption solution.

The Thornton procedure calls for 3 cc of extract while the others call for 2 cc. Thus 3 cc of the standards made up in Thornton's extractant were also used, giving rise to denser precipitates for equivalent concentrations than with the other extractants. The effective range of Thornton's extractant was, therefore, somewhat reduced in the upper levels of concentration.

The absence of free sodium ions to suppress the solubility of the cobaltinitrite in the 50% ethyl alcohol (Purvis absorption solution) resulted in less dense precipitates for equivalent concentrations than with any of the extractants.

2. Phosphorus

a) Phosphorus reagents

1) 2% ammonium molybdate in 3.78 N HCl prepared according to Kuhnke, et al (43). This is used directly with Thornton's phosphorus extractant, Hester II, and Purvis' absorption solution.

2) 2% ammonium molybdate in 5.0 N HCl (for use with Hester I).

3) 2% ammonium molybdate in 7.0 N HCl (for use with Morgan's extractant).

4) Dry powdered stannous oxalate (43, 48).

5) General notes on phosphorus reagents:

It was necessary to use three different formulations of the ammonium molybdate reagent. Hester I and Morgan's Universal Extractant are both so highly buffered with the sodium ion that they reduced the acidity of the developed test, using the first reagent described above, to the point where the molybdate ion was itself reduced and a blue color was secured in a blank test solution (24). According to Woods and Mellon (54), this reaction will occur above pH 0.5. This development of color in a blank test solution may be eliminated either by reducing the concentration of molybdate ion in the developed test solution or by increasing the acidity (within limits) of the developed test.

If the first method, that of reducing the proportion of molybdate ion in the developed test solution, is used, the conditions of the test are difficult to control. A slight change in concentration of molybdate ion resulting from slight inaccuracies in measurement will cause abnormal changes in the intensity of the color produced (39). Furthermore, tests made in a series of standards increase in color intensity at a much more rapid rate than the concentration of phosphorus in the standards, thereby reducing range and the distinctness of color differences for visual reading.

These difficulties are overcome when the second method, that of increasing the acidity of the developed test is used. Woods and Mellon (54) recommend using a concentration of acid in the molybdate reagent slightly in excess of that required to eliminate a blue color in a blank test. An excess concentration of chloride ions, as well as excess acidity, will reduce the intensity of color. Care must be taken not to increase the normality of HCl too greatly.

With the ratio of reagent to test solution which was used in this procedure a concentration of 5.0 N HCl was required with Hester I. With Morgan's extractant 7.0 N HCl was needed.

b) Phosphorus procedure:

To 4 cc of extract in a flat-bottomed vial add 1 cc of the ammonium molybdate reagent. Mix thoroughly, Add a small amount (as much as will stay on ¼ inch of the small end of an ordinary flat tooth pick) of the dry stannous oxalate.

Invert the tube gently twice and allow to stand. If, at the end of one minute, there is a region of color fading in contact with the stannous oxalate, take a reading on the upper portion of the solution immediately.

If there is a region of color intensification immediately above the stannous oxalate, invert the vial gently again and allow to stand 1 minute longer. Again take the reading only if there is incipient fading in contact with the stannous oxalate. If not, invert gently several times and allow to stand 2 minutes longer. Intensification will be complete and the reading may be taken directly (26, 54). (See Reading Method below.)

This method of reducing the phosphorus-molybdate complex by stages enables the full color to be brought out with a minimum amount of stannous oxalate in solution (43, 48). An excess of the stannous ion causes turbidity, especially at low concentrations of phosphorus (54). The oxalate ion increases the rate of fading (54). It is important not to get too much stannous oxalate into solution, particularly in solutions of low phosphorus concentration.

c) Reading method for phosphorus:

Phosphorus test solutions were read in this study by comparing colors directly with standards of known concentration. It was found necessary to make up the standards in the particular extractant with which comparison was being made. Test reagents were added to a series of standards at the same time that they were added to the unknown test solutions, and the color was brought out in a similar manner. The color comparison was made by observing the tubes against the light emitted by a daylight lamp.

3. Calcium

a) Calcium reagents:

1) Saturated ammonium oxalate stock solution is prepared by dissolving about 5 gms of ammonium oxalate in 100 cc of distilled water. Add 1 cc of NH_4OH and 5 cc of glycerine (26, 47).

2) Ammonium oxalate test solution is prepared by diluting 6 cc of the stock solution to 40 cc with distilled water. The NH_4OH assures a pH above 4.0 in the developed test. Calcium oxalate is soluble below pH 4.0 (2). The glycerine increases the viscosity of the test solution and gives a finer grained precipitate conducive to greater uniformity of readings (2).

b) Calcium procedure:

To 1 cc of extract in a flat-bottomed vial add 4 cc of the ammonium oxalate test solution. Mix immediately with a rotary motion. Do not shake vigorously. Read in 1 to 5 minutes (26, 47).

c) Reading method for calcium:

In this study readings were made in the same manner as with potassium. The proportions of reagent and extract were modified to give a final volume of 5 cc to facilitate this mode of reading. The calibration of the black and yellow lines was checked frequently against separate series of standards made up in each extracting solution. The resultant calibration of lines was similar for all extractants.

4. Magnesium

a) Magnesium reagents:

1) Titan yellow stock solution (2). Dissolve 0.30 gms of titan yellow and 0.2 gms of Na H_2PO_4 - H_2O in 100 cc of 50% methyl alcohol.

2) Titan yellow test solution. At the time of use, dilute 1 part of stock solution with 5 parts of distilled water.

3) Basic sucrose (2). Dissolve 83.3 gms of NaOH and 50 gms of sucrose separately in distilled water. Combine the two solutions and make up to 1 liter with distilled water.

b) Magnesium procedure:

To 2 cc of extract add 3 cc of the titan yellow test solution and 5 cc of basic sucrose. Mix gently but thoroughly. Read after 1 minute.

Magnesium is precipitated as the hydroxide upon which the titan yellow is adsorbed to form a lake. Excess alkali is added to prevent precipitation of aluminum. Sucrose prevents the precipitation of calcium. Methyl alcohol promotes more complete precipitation of magnesium hydroxide.

The phosphate ion intensifies the color that is developed. To avoid variations in color intensity resulting from variations in concentration of the phosphate ion in the extract, an excess of phosphate is added as sodium phosphate in the titan yellow reagent.

This titan yellow stock reagent was used directly in the procedure described by Barber (1). In the work reported here the stock reagent was diluted 1 to 5 in order to reduce the concentration of all components in the developed test solution. This resulted in a finer-grained suspension, more amenable to color comparison. As a result the upper limit of concentrations on which color distinctions could be made was increased from 60 ppm to 150 ppm of MgO (2, 17).

Pyrex test tubes graduated at 2, 5, and 10 cc were used to facilitate measurement of extract and reagents.

c) Reading method for magnesium:

In this study, readings were made by direct comparison with fresh standards made up simultaneously with the unknown test solutions. Standards were made up in the particular extracting solution with which comparison was being made. Except for tests made up in Na ClO_4, the color of equivalent standards was comparable.

G. STANDARDS

For purposes of a balance sheet or growth curve calibration of soil test results, the color charts published in connection with the various soil testing procedures (39, 47, 48) were found to be inadequately graduated.

No satisfactory permanent color standards were found for phosphorus or magnesium. Hester's methylene blue standards (27) for phosphorus were not satisfactorily comparable in color with test solutions developed in the various extractants, particularly at higher levels of concentration. Attempts were made to develop permanent phosphorus color standards using the reduced molybdate ion itself (38), and the reduced phosphorus-molybdate complex (33). These proved little more permanent than those made up in standard phosphorus solutions (54).

The turbidity chart used in the reading method for potassium and calcium (p. 19) obviated permanent standards for these two nutrients. It was necessary to check the calibration of the black and yellow lines occassionally to maintain uniformity of readings. Any marked and consistent shift in the calibration of the lines for potassium indicated the need for renewing the cobaltinitrite reagent.

The blue color of tests in standard phosphorus solutions of low concentration faded rapidly in a matter of one or two hours after being developed. The colored precipitate in developed magnesium standard solutions gradually flocculated over a period of several hours into coarse particles with which color comparison was impossible. Thus it was necessary to make up phosphorus and magnesium standards each time a group of soils was tested. Calcium and potassium standards were required periodically.

To facilitate the making up of these standards, concentrated stock standards were made up in .05 N HCl as follows:

1. Potassium (1,000 ppm K_2O)

   1.6 gms KCl in 1 liter of 0.05 N HCl.

2. Phosphorus (160 ppm P_2O_5)

   0.360 gms $K_2H\ PO_4$ in 1 liter of 0.05 N HCl.

3. Calcium (10,000 ppm CaO)

   6.643 gms $Ca\ (C_2H_3O_2)_2 \cdot H_2O$ in 200 cc of 0.05 N HCl.

4. Magnesium (1,500 ppm MgO)

   1.8341 gms $MgSO_4 \cdot 7\ H_2O$ in 200 cc of 0.05 N HCl.

1. Working standards:

The above stock standards were diluted 1 to 9 with each extracting solution, to give a group of working standards in each extractant containing respectively, 100 ppm K_2O, 16 ppm P_2O_5, 1,000 ppm CaO and 150 ppm MgO. In the case of Thornton's potassium extractant, the dilution was made with 15% $NaNO_2$, and the sodium cobaltinitrite was not added until the time of developing the standard test. A mixture of equal parts of 95% ethyl alcohol and distilled water was used to make the dilution with the Purvis absorption solution.

2. Test standards:

Whenever calibration readings or color comparisons were to be made using any particular extracting solution, a series of test standards was prepared from the "working" standard made up in that extractant. These test standards were developed simultaneously with the unknowns in the case of phosphorus and magnesium, where direct color comparison was made.

Proportions of working standard to extractant and the procedures for developing test standards are shown in Table 3. The standards as described in Table 3 were used in the final phases of the work, and are graduated as closely as is consistent with duplicability of visual readings.

Table 3 - Preparation of standard test solutions of P_2O_5, K_2O, CaO and MgO used in calibration of turbidity charts and for color comparison with unknown test solutions.

P_2O_5			CaO		
ppm	Working Standard	Extractant	ppm	Working Standard	Extractant
0.4	0.1 cc	3.9 cc	50	0.05 cc	0.95 cc
1.0	0.25 "	3.75 "	200	0.2 "	0.8 "
2.0	0.5 "	3.5 "	400	0.4 "	0.6 "
3.0	0.75 "	3.25 "	600	0.6 "	0.4 "
4.0	1.0 "	3.0 "	800	0.8 "	0.2 "
6.0	1.5 "	2.5 "	1000	1.0 "	0.0 "
8.0	2.0 "	2.0 "			
10.0	2.5 "	1.5 "			
12.0	3.0 "	1.0 "			
16.0	4.0 "	0.0 "			

K_2O					MgO		
	All extractants except Thornton's		Thornton's extractant				
ppm	Working Std.	Extractant	Working Std.	Extractant	ppm	Working Std.	Extractant
					7.5	0.1 cc	1.9 cc
10	0.2 cc	1.8 cc	0.3 cc	2.7 cc	15.0	0.2 "	1.8 "
20	0.4 "	1.6 "	0.6 "	2.4 "	30.0	0.4 "	1.6 "
30	0.6 "	1.4 "	0.9 "	2.1 "	45.0	0.6 "	1.4 "
40	0.8 "	1.2 "	1.2 "	1.8 "	60.0	0.8 "	1.2 "
50	1.0 "	1.0 "	1.5 "	1.5 "	75.0	1.0 "	1.0 "
60	1.2 "	0.8 "	1.8 "	1.2 "	90.0	1.2 "	0.8 "
80	1.6 "	0.4 "	2.4 "	0.6 "	120.0	1.6 "	0.4 "
100	2.0 "	0.0 "	3.0 "	0.0 "	150.0	2.0 "	0.0 "

The volumes shown above for K_2O (all extractants except Thornton's) were doubled for Purvis' absorption solution so that the final volume was 4 cc.

These test standards were made up in 14 mm x 75 mm flat-bottomed vials (or in graduated Pyrex test tubes in the case of magnesium). The tests were developed in exactly the same manner as is described in Part F, - except in the case of Thornton's potassium extractant.

Thornton's potassium extractant - Development of test standards:

To 3 cc of the standard test solution was added 0.5 cc of a mixture of 3 parts of the stock cobaltinitrite solution and 7 parts of 40% formaldehyde. These were shaken immediately. 1.5 cc of anhydrous isopropyl alcohol was added gently down the side of the vial. After mixing, the standards were allowed to stand 3 minutes before reading.

H. PLANT TISSUE TEST PROCEDURE

The plant tissue test procedure used in this study was the one described by Thornton, Connor and Fraser (47).

PART II

RESULTS

A. RESIDUAL FERTILIZER TREATMENTS

Experimental field plots on which differential fertilizer treatments have been applied systematically over a sufficiently long period of time for residual accumulations of fertilizer nutrients to occur are useful in evaluating the sensitivity of a group of extractants to variations in the soil supply of these nutrients.

Supplemental yield data from such experiments makes it possible to establish whether or not a given soil test covers a range of values that is significant from the standpoint of practical crop response. If the sensitive reading range of the test is too low or too high to coincide with the range over which crops show response to fertilizer applications, it may be necessary to alter the ratio of soil to extracting solution or to dilute the extract before testing. On the other hand, test values may fall within the significant range and yet be erratic and show no relationship to crop response. In that case, the test may be measuring a form of the nutrient that is not significant in crop growth. A different extractant may need to be found (6).

In some cases levels of response and non-response may be determined tentatively for specific soils by correlations with the performance of a crop on an established experiment where specific fertilizer treatments have been applied over a period of years.

A number of established field experiments with varying rates of fertilization and liming were available at several substations of the Virginia Agricultural Experiment Station. These experiments had been running a number of years and were located on important soil types representing the three soil provinces of the state.

In Tables 4 through 27, the treatments for these experiments are shown. Also shown are the rapid soil test values, plant tissue test results (for corn only), and yields for the 1941 (and/or 1942) crop year. The soil test values were determined on soil samples taken during the fall or spring preceding the crop for which yields are tabulated. The testing procedures described in PART I were used.

Table 4 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Dunmore silt loam
Location: - Virginia Agricultural Experiment Station
Blacksburg

Crop: - Corn
Crop year: - 1942

Experiment: - "Old Rotation" fertilizer ratio experiment with corn, wheat, clover, and clover and timothy in a 4-year rotation. Soil samples were taken in the spring prior to establishment of the schedule of treatments listed on the unfertilized end of the "Old Rotation." Soil samples represent plots that had received no fertilizer (except 1 ton per acre of dolomitic limestone every four years) from 1914 to 1942.

	K_2O extracted				
Fertilizer treatments	Bray	Thornton	Morgan	Hester I	Hester II
Check	80	40	80	30	30
400 lbs. 0-12-12	120	40	80	30	30
" 2-12-12	80	40	80	30	30
" 4-12-12	120	40	120	30	30
" 8-12-12	120	40	80	30	30
" 12-12-12	120	40	120	30	30
" 4-0-12	120	40	80	30	30
" 4-18-12	80	40	80	30	30
" 4-24-12	80	40	80	30	30
" 8-24-12	120	40	80	30	30
" 4-12-0	80	40	120	30	30
" 4-12-6	80	40	80	30	30
" 4-12-18	80	40	80	30	30
" 4-12-24	80	40	80	30	30

	P_2O_5 extracted			
Fertilizer treatments	Thornton	Morgan	Hester I	Hester II
Check	16	12	8	8
400 lbs. 0-12-12	16	12	8	8
" 2-12-12	20	12	12	16
" 4-12-12	24	24	8	8
" 8-12-12	20	32	8	12
" 12-12-12	24	16	12	12
" 4-0-12	16	32	12	12
" 4-18-12	16	16	12	12
" 4-24-12	20	20	12	8
" 8-24-12	16	24	12	12
" 4-12-0	16	24	8	8
" 4-12-6	20	12	8	12
" 4-12-18	24	16	12	8
" 4-12-24	16	24	8	8

Table 4 - "Old Rotation" - Blacksburg - Corn - Cont'd.

Fertilizer treatments	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	1680	2240	1260	840
400 lbs. 0-12-12	1680	2240	1260	1260
" 2-12-12	1680	2240	1260	1260
" 4-12-12	1680	2800	1680	1260
" 8-12-12	2240	2800	1260	1680
" 12-12-12	2240	2800	1260	1680
" 4-0-12	2240	2800	1680	1680
" 4-18-12	2240	3360	1680	1680
" 4-24-12	2240	3360	1680	1680
" 8-24-12	2240	2800	1680	1680
" 4-12-0	2240	2800	1680	1680
" 4-12-6	1680	2240	1680	1260
" 4-12-18	1680	2240	1260	1260
" 4-12-24	1680	2240	1260	1260

Fertilizer treatments	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	60	120	135	135
400 lbs. 0-12-12	60	180	135	135
" 2-12-12	60	180	180	135
" 4-12-12	60	180	180	180
" 8-12-12	120	120	135	180
" 12-12-12	120	180	135	180
" 4-0-12	60	180	180	135
" 4-18-12	120	180	135	135
" 4-24-12	60	180	135	135
" 8-24-12	60	120	180	135
" 4-12-0	60	120	135	180
" 4-12-6	60	180	135	180
" 4-12-18	60	180	180	180
" 4-12-24	60	180	180	135

Table 5 - "Old Rotation" - Blacksburg - Plant Tissue tests and yield of corn in 1942.

Fertilizer treatments	Yield Bu./A	6/12/42 NO3	P2O5	K2O	8/20/42 NO3	P2O5	K2O
Check	35.7	H	H	VH	L	H	L
400 lbs. 0-12-12	57.8	H	H	VH	VL	VH	VH
" 2-12-12	65.3	H	H	H	VL	H	VH
" 4-12-12	56.9	H	M	VH	VL	M	H
" 8-12-12	55.9	H	M	H	L	M	VL
" 12-12-12	58.6	H	M	VH	VL	H	M
" 4-0-12	44.0	H	M	VH	VL	M	M
" 4-18-12	69.3	H	H	VH	VL	M	M
" 4-24-12	63.5	H	H	VH	L	M	H
" 8-24-12	65.6	H	VH	H	L	M	M
" 4-12-0	44.3	H	M	VH	L	M	L
" 4-12-6	52.4	H	H	VH	L	L	M
" 4-12-18	65.8	H	H	VH	VL	M	M
" 4-12-24	49.6	M	H	H	VL	L	M

Table 6 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions and pounds per acre of available soil nitrogen, based on organic matter content of the soil.

Soil type: - Dunmore silt loam
Location: - Virginia Agricultural Experiment Station, Blacksburg
Crop: - Corn
Crop year: - 1941

Experiment: - Available Plant Food Experiment. Corn, wheat and red clover in a 3-year rotation with varying amounts of phosphoric acid and potash. Fertilizer treatments listed had been applied on corn and wheat since the experiment was started in 1936.

Fertilizer treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Check	400	40	160	180	150
500 lbs. 12-0-12	400	40	120	120	120
" 12-6-12	400	40	240	240	210
" 12-12-12	400	40	120	120	120
" 12-24-12	400	160	80	120	120
" 12-12-0	400	40	160	60	90
" 12-12-20	400	240	280	180	210
" 12-12-40	400	400	400	300	300

Fertilizer treatments	P_2O_5 extracted			
	Thornton	Morgan	Hester I	Hester II
Check	16	8	8	8
500 lbs. 12-0-12	8	8	8	8
" 12-6-12	16	8	8	16
" 12-12-12	48	16	8	16
" 12-24-12	80	48	64	64
" 12-12-0	24	24	24	16
" 12-12-20	48	16	16	24
" 12-12-40	24	8	16	24

Fertilizer treatments	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	2240	3360	420	840
500 lbs. 12-0-12	2240	2800	420	840
" 12-6-12	2240	2800	2940	2520
" 12-12-12	2240	2240	2940	2520
" 12-24-12	2240	2240	2940	2940
" 12-12-0	2240	2800	2520	2940
" 12-12-20	2240	3360	2520	2520
" 12-12-40	2240	3360	2100	2100

Table 6 - Blacksburg - Corn - Cont'd.

Fertilizer treatments		MgO extracted: Bray	Morgan	Hester I	Hester II	Organic Matter	Available Nitrogen*
		#/A.	#/A.	#/A.	#/A.	%	%
Check		120	240	225	180	2.43	60
500 lbs.	12-0-12	60	180	135	135	1.98	50
"	12-6-12	120	180	180	180	2.25	56
"	12-12-12	30	120	135	135	2.31	58
"	12-24-12	60	120	135	90	2.09	52
"	12-12-0	60	180	135	135	1.93	48
"	12-12-20	60	180	135	135	2.36	59
"	12-12-40	60	120	90	90	2.10	53

* Nitrogen calculated as 5% of organic matter, with 2.5% nitrified annually (28).

Table 7 - Blacksburg - Corn - Plant tissue tests and yield of corn in 1941.

Fertilizer treatments		Yield Bu./A	7/3/41 NO_3	7/3/41 P_2O_5	7/3/41 K_2O	7/21/41 NO_3	7/21/41 P_2O_5	7/21/41 K_2O
Check		61.8	H	VH	H	L	H	M
500 lbs.	12-0-12	83.2	H	M	H	H	H	H
"	12-6-12	65.4	H	H	H	H	H	H
"	12-12-12	71.3	H	H	H	H	M	H
"	12-24-12	68.9	H	M	H	H	H	M
"	12-12-0	68.9	M	L	H	H	H	H
"	12-12-20	77.3	H	M	H	H	H	H
"	12-12-40	68.3	VH	VH	H	H	H	VH

Fertilizer was applied broadcast and disked into the soil at time of planting.

Corn was about 40 inches high when the first tissue tests were made and it was just beginning to silk and tassel at time of second testing.

Table 8 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Dunmore silt loam
Crop: - Wheat
Location: - Virginia Agricultural Experiment Station Blacksburg
Crop year: - 1941

Experiment: - Available Plant Food Experiment. Corn, wheat and red clover in a 3-year rotation with varying amounts of phosphoric acid and potash. Fertilizer treatments listed had been applied on corn and wheat since the experiment was started in 1936.

Fertilizer treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Check	400	40	240	120	180
500 lbs. 12-0-12	400	40	200	180	180
" 12-6-12	400	40	200	180	150
" 12-12-12	400	40	360	150	120
" 12-24-12	400	40	320	210	210
" 12-12-0	400	40	160	90	120
" 12-12-20	400	120	160	120	90
" 12-12-40	400	200	360	240	270

Fertilizer treatments	P_2O_5 extracted			
	Thornton	Morgan	Hester I	Hester II
Check	16	16	8	16
500 lbs. 12-0-12	8	16	3	16
" 12-6-12	16	8	8	8
" 12-12-12	32	24	8	24
" 12-24-12	24	16	16	16
" 12-12-0	8	24	3	16
" 12-12-20	24	16	8	8
" 12-12-40	8	16	16	24

Fertilizer treatments	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	2240	2240	840	1260
500 lbs. 12-0-12	2240	2240	840	1260
" 12-6-12	2240	2240	840	840
" 12-12-12	2240	2240	840	840
" 12-24-12	2240	2240	1260	1680
" 12-12-0	2240	2240	840	840
" 12-12-20	2240	2240	840	840
" 12-12-40	2240	2240	1680	1260

Table 8 - Blacksburg - Wheat - Cont'd.

Fertilizer treatments	MgO extracted: Bray	Morgan	Hester I	Hester II	Yield Bus./A.
Check	30	60	90	90	16.7
500 lbs. 12-0-12	30	30	45	45	23.3
" 12-6-12	30	30	45	45	26.1
" 12-12-12	30	30	90	45	20.6
" 12-24-12	30	30	45	45	18.9
" 12-12-0	30	30	45	22	16.7
" 12-12-20	30	30	45	45	25.6
" 12-12-40	30	30	45	22	25.6

Fertilizer applied broadcast and disked into the soil before wheat was drilled.

Table 9 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Dunmore silt loam
Location: - Virginia Agricultural Experiment Station
Blacksburg

Crop: - Clover
Crop year: - 1941

Experiment: - Available Plant Food Experiment. Corn, wheat, and red clover in a 3-year rotation with varying amounts of phosphoric acid and potash. Fertilizer treatments listed had been applied on corn and wheat since the experiment was started in 1936.

Residual Fertilizer treatments	K_2O extracted Bray	Thornton	Morgan	Hester I	Hester II
Check	400	40	320	210	180
500 lbs. 12-0-12	400	40	320	180	210
" 12-6-12	400	40	400	150	180
" 12-12-12	400	40	280	120	240
" 12-24-12	400	40	280	270	180
" 12-12-0	400	40	280	90	120
" 12-12-20	400	40	280	150	240
" 12-12-40	400	120	400	270	270

Residual Fertilizer treatments	P_2O_5 extracted Thornton	Morgan	Hester I	Hester II
Check	16	24	16	24
500 lbs. 12-0-12	3	8	16	8
" 12-6-12	32	16	24	24
" 12-12-12	64	24	16	32
" 12-24-12	128	64	80	96
" 12-12-0	32	16	24	24
" 12-12-20	8	8	3	3
" 12-12-40	32	16	16	16

Residual Fertilizer treatments	CaO extracted Bray	Morgan	Hester I	Hester II
Check	2240	3360	840	1260
500 lbs. 12-0-12	2240	2240	1260	840
" 12-6-12	2240	2800	1680	840
" 12-12-12	2240	3360	1260	840
" 12-24-12	2240	2800	1260	1260
" 12-12-0	2240	2240	840	1260
" 12-12-20	2240	2800	840	840
" 12-12-40	2240	2240	840	1260

Table 9 - Blacksburg - Clover - Cont'd.

Residual Fertilizer treatments	MgO extracted: Bray	Morgan	Hester I	Hester II	Hay Lbs./A.
Check	60	180	180	180	3000
500 lbs. 12-0-12	60	120	135	135	2200
" 12-6-12	60	120	135	90	2500
" 12-12-12	60	60	90	135	2300
" 12-24-12	30	60	135	45	2467
" 12-12-0	60	60	180	90	1600
" 12-12-20	60	120	135	135	2767
" 12-12-40	60	60	135	135	2367

Table 10 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Berks silt loam — Crop: - Corn
Location: - Virginia Agricultural Experiment Station, Staunton — Crop year: - 1942

Experiment: - Available Plant Food Experiment, with varying rates of phosphoric acid and potash. Soil treatments listed had been applied 5 years in a period of 7 years.

Treatments	Corn Bu./A.	P_2O_5 extracted: Morgan	Hester I	Hester II	Thornton
Check	28.5	0	3	3	3
500 lbs. 12-0-12	46.0	0	16	16	0
" 12-6-12	56.0	0	24	24	3
" 12-12-12	58.5	3	24	24	0
" 12-20-12	58.1	8	24	24	3
" 12-12-0	40.5	24	16	48	0
" 12-12-10	47.0	16	16	24	3
" 12-12-20	54.5	24	16	16	0
" 12-12-40	54.5	16	8	16	0

Treatments	K_2O extracted: Bray	Thornton	Morgan	Hester I	Hester II
Check	160	40	160	180	180
500 lbs. 12-0-12	240	40	160	150	180
" 12-6-12	160	40	280	240	180
" 12-12-12	320	40	240	180	150
" 12-20-12	160	40	280	180	180
" 12-12-0	160	40	160	90	240
" 12-12-10	200	40	280	90	180
" 12-12-20	280	40	320	90	150
" 12-12-40	360	40	320	120	150

Table 10 - Staunton - Corn - Cont'd.

Treatments	CaO extracted Bray	Morgan	Hester I	Hester II
Check	1680	3360	1260	1260
500 lbs. 12-0-12	1680	3360	1680	1260
" 12-6-12	1680	3920	1260	1260
" 12-12-12	3920	2800	1680	420
" 12-20-12	3920	3920	1680	1260
" 12-12-0	3360	2800	1680	1260
" 12-12-10	3360	3920	1680	840
" 12-12-20	2800	2240	1680	1260
" 12-12-40	2800	3920	1260	1260

Treatments	MgO extracted Bray	Morgan	Hester I	Hester II
Check	180	180	225	180
500 lbs. 12-0-12	180	180	225	225
" 12-6-12	180	180	225	225
" 12-12-12	180	240	225	225
" 12-20-12	180	180	225	225
" 12-12-0	180	240	270	270
" 12-12-10	180	180	270	225
" 12-12-20	180	180	270	225
" 12-12-40	180	180	270	270

Table 11 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Berks silt loam　　Crop: - Wheat
Location: - Virginia Agricultural Experiment Station　　Crop year: - 1942
Staunton

Experiment: - Available Plant Food Experiment with varying rates of phosphoric acid and potash. Soil treatments listed had been applied during 4 years of a 6-year period.

Treatments	Wheat Bus./A	P_2O_5 extracted Morgan	Hester I	Hester II	Thornton
Check	8.1	16	16	8	3
500 lbs. 12-0-12	9.6	16	8	8	16
" 12-6-12	19.0	8	8	16	8
" 12-12-12	24.3	24	24	24	24
" 12-20-12	24.5	48	64	64	24
" 12-12-0	15.5	32	8	24	16
" 12-12-10	17.6	32	32	32	8
" 12-12-20	22.0	24	24	24	32
" 12-12-40	23.0	24	24	24	24

Treatments	K_2O extracted Bray	Thornton	Morgan	Hester I	Hester II
Check	120	40	80	60	60
500 lbs. 12-0-12	120	40	80	240	90
" 12-6-12	120	40	80	180	120
" 12-12-12	200	40	80	180	120
" 12-20-12	160	40	120	90	90
" 12-12-0	160	40	80	90	90
" 12-12-10	120	40	80	60	60
" 12-12-20	120	40	80	60	60
" 12-12-40	120	40	120	60	60

Table 11 - Staunton - Wheat - Cont'd.

Treatments	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	560	1680	1260	1260
500 lbs. 12-0-12	560	560	1260	1260
" 12-6-12	560	560	1260	1680
" 12-12-12	1120	1120	1260	1260
" 12-20-12	560	1120	1680	1680
" 12-12-0	560	1120	1680	1260
" 12-12-10	560	1120	1260	1260
" 12-12-20	560	1120	1260	1260
" 12-12-40	560	1120	1260	1260

Treatments	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	180	180	225	180
500 lbs. 12-0-12	180	180	270	180
" 12-6-12	180	180	270	225
" 12-12-12	180	180	225	180
" 12-20-12	180	180	270	180
" 12-12-0	180	180	270	180
" 12-12-10	180	180	270	225
" 12-12-20	120	120	180	180
" 12-12-40	180	180	270	225

Table 12 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Dunmore silt loam
Location: - Virginia Agricultural Experiment Station
Glade Spring

Crop: - Corn
Crop year: - 1941

Experiment: - Fertilizer experiment with corn, wheat, and red clover grown in rotation; with and without lime. Lime applied every third year before corn. Fertilizers applied on corn and wheat but not on clover since experiment was started in 1930.

Treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
With lime					
Check	280	40	80	120	120
300 lbs. 0-16-0	240	40	160	60	120
" 0-16-4	120	40	280	120	120
" 4-16-0	280	40	120	180	180
" 4-16-4	280	120	360	210	180
Without lime					
Check	400	40	240	120	150
300 lbs. 0-16-0	320	40	160	150	150
" 0-16-4	200	40	160	150	120
" 4-16-0	240	40	160	90	180
" 4-16-4	240	40	120	90	90

Treatments	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
With lime				
Check	0	3	0	3
300 lbs. 0-16-0	0	3	3	0
" 0-16-4	3	3	3	3
" 4-16-0	0	0	3	3
" 4-16-4	3	3	0	3
Without lime				
Check	0	3	0	0
300 lbs. 0-16-0	3	0	0	0
" 0-16-4	0	3	3	3
" 4-16-0	3	0	0	3
" 4-16-4	0	3	3	3

Table 12 - Glade Spring - Corn - Cont'd.

Treatments	CaO extracted Bray	Morgan	Hester I	Hester II	pH
With lime					
Check	1120	1120	1680	1260	7.6
300 lbs. 0-16-0	2240	3920	1260	1260	7.7
" 0-16-4	1120	1120	1260	1260	7.4
" 4-16-0	2240	2240	1260	840	7.5
" 4-16-4	1120	1120	1260	840	7.4
Without lime					
Check	1680	3360	1260	2100	6.1
300 lbs. 0-16-0	560	1680	1260	2100	6.1
" 0-16-4	1680	3360	1260	2100	5.9
" 4-16-0	560	1680	1260	2100	6.0
" 4-16-4	560	1680	1260	2100	6.4

Treatments	MgO extracted Bray	Morgan	Hester I	Hester II
With lime				
Check	180	240	360	225
300 lbs. 0-16-0	180	180	270	225
" 0-16-4	180	240	270	225
" 4-16-0	240	240	270	180
" 4-16-4	240	240	270	225
Without lime				
Check	240	360	360	225
300 lbs. 0-16-0	240	300	225	270
" 0-16-4	180	240	225	180
" 4-16-0	240	240	225	180
" 4-16-4	300	300	270	225

Table 13 - Glade Spring - Corn - Plant tissue tests and yield of corn in 1941.

Treatments	Bu./A.	7/5/41 NO_3	7/5/41 P_2O_5	7/5/41 K_2O	7/19/41 NO_3	7/19/41 P_2O_5	7/19/41 K_2O
With lime							
Check	32.9	H	VL	L	H	L	M
300 lbs. 0-16-0	60.9	H	M	H	H	M	L
" 0-16-4	59.2	H	L	M	H	VH	L
" 4-16-0	55.7	H	M	H	M	M	VL
" 4-16-4	61.7	H	L	M	H	H	L
Without lime							
Check	14.6	H	VL	M	M	L	M
300 lbs. 0-16-0	43.4	H	M	H	M	H	M
" 0-16-4	48.9	H	M	H	L	L	M
" 4-16-0	53.7	H	M	H	VL	M	VL
" 4-16-4	54.0	H	L	M	H	H	M

Remarks: - Potash deficiency symptoms were evident on July 19 on the check and 4-16-0 plots.

Corn was about 40 inches high when first tests were made and it was just beginning to silk and tassel when second tests were made.

Table 14 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Dunmore silt loam
Location: - Virginia Agricultural Experiment Station
Glade Spring

Crop: - Wheat
Crop year: - 1941

Experiment: - Fertilizer experiment with corn, wheat, and red clover grown in rotation; with and without lime. Lime applied every third year before corn. Fertilizers applied on corn and wheat but not on clover since experiment was started in 1930.

Treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
With lime					
Check	160	40	200	90	90
300 lbs. 0-16-0	280	40	160	60	90
" 0-16-4	160	40	160	90	60
" 4-16-0	80	40	40	90	60
" 4-12-4	160	40	40	90	90
" 4-16-4	120	40	40	90	90
Without lime					
Check	240	40	40	180	180
300 lbs. 0-16-0	240	40	120	180	120
" 0-16-4	280	40	160	180	120
" 4-16-0	160	40	160	150	150
" 4-12-4	280	40	200	120	120
" 4-16-4	200	40	40	120	120

Treatments	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
With lime				
Check	3	1	8	32
300 lbs. 0-16-0	8	8	3	32
" 0-16-4	8	8	8	80
" 4-16-0	16	3	3	8
" 4-12-4	3	3	8	3
" 4-16-4	8	8	8	16
Without lime				
Check	8	8	8	8
300 lbs. 0-16-0	8	8	3	16
" 0-16-4	3	8	3	3
" 4-16-0	3	8	3	16
" 4-12-4	3	3	8	16
" 4-16-4	16	3	3	8

Table 14 - Glade Spring - Wheat - Cont'd.

Treatments	CaO extracted: Bray	Morgan	Hester I	Hester II	pH
With lime					
Check	1120	560	2100	420	7.0
300 lbs. 0-16-0	2240	2800	2520	2100	6.9
" 0-16-4	1120	2800	2100	1680	6.9
" 4-16-0	3920	2800	2100	1680	7.0
" 4-12-4	2800	2240	1680	1260	6.8
" 4-16-4	3920	2800	2520	1680	6.8
Without lime					
Check	560	1680	420	1260	5.9
300 lbs. 0-16-0	140	1680	420	1680	6.1
" 0-16-4	1120	1120	420	1260	6.1
" 4-16-0	560	1120	420	1260	6.0
" 4-12-4	140	560	420	420	6.0
" 4-16-4	560	560	420	1260	6.2

Treatments	MgO extracted: Bray	Morgan	Hester I	Hester II	Yield Bu./A
With lime					
Check	360	300	450	360	14.0
300 lbs. 0-16-0	180	240	270	180	28.3
" 0-16-4	360	360	360	360	26.3
" 4-16-0	300	360	360	360	31.0
" 4-12-4	240	240	360	360	32.0
" 4-16-4	180	180	270	135	36.3
Without lime					
Check	480	600	450	450	5.7
300 lbs. 0-16-0	120	180	135	90	20.0
" 0-16-4	360	480	450	450	25.0
" 4-16-0	240	360	450	360	23.3
" 4-12-4	120	180	135	135	23.7
" 4-16-4	180	180	180	135	31.3

Table 15 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Dunmore silt loam
Location: - Virginia Agricultural Experiment Station
Glade Spring

Crop: - Clover
Crop year: - 1941

Experiment: - Fertilizer experiment with corn, wheat, and red clover grown in rotation; with and without lime. Lime applied every third year before corn. Fertilizer applied on corn and wheat but not on clover since experiment was started in 1930.

Residual fertilizer treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
With lime					
Check	200	40	120	120	150
300 lbs. 0-16-0	160	40	80	90	120
" 0-16-4	160	40	160	120	150
" 4-16-0	80	40	200	150	150
" 4-12-4	160	40	160	150	120
" 4-16-4	160	40	200	150	150
Without lime					
Check	80	40	80	150	180
300 lbs. 0-16-0	160	40	120	180	180
" 0-16-4	200	40	160	120	180
" 4-16-0	120	40	200	150	150
" 4-12-4	160	40	200	150	150
" 4-16-4	40	40	200	150	120

Residual fertilizer treatments	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
With lime				
Check	3	0	3	3
300 lbs. 0-16-0	3	3	8	8
" 0-16-4	8	8	3	8
" 4-16-0	3	3	3	3
" 4-12-4	8	3	8	3
" 4-16-4	3	0	3	3
Without lime				
Check	16	0	0	8
300 lbs. 0-16-0	3	3	3	0
" 0-16-4	16	8	3	0
" 4-16-0	8	3	0	8
" 4-12-4	8	0	0	3
" 4-16-4	8	3	3	0

Table 15 - Glade Spring - Clover - Cont'd.

Residual fertilizer treatments	CaO extracted: Bray	Morgan	Hester I	Hester II	pH
With lime					
Check	1680	1120	420	420	7.0
300 lbs. 0-16-0	560	560	840	840	6.9
" 0-16-4	560	1120	840	840	6.8
" 4-16-0	560	1120	840	840	6.9
" 4-12-4	560	2240	840	420	7.0
" 4-16-4	560	1120	840	840	6.9
Without lime					
Check	2240	1120	420	420	5.8
300 lbs. 0-16-0	1680	1680	420	420	6.1
" 0-16-4	1680	1680	420	420	5.8
" 4-16-0	2240	1680	420	420	5.7
" 4-12-4	1680	1680	420	420	5.9
" 4-16-4	1680	1120	420	420	6.0

Residual fertilizer treatments	MgO extracted: Bray	Morgan	Hester I	Hester II	Yield lbs./A.
With lime					
Check	180	360	180	135	1494
300 lbs. 0-16-0	180	180	225	180	1784
" 0-16-4	180	240	225	135	2386
" 4-16-0	300	300	135	225	2117
" 4-12-4	120	120	225	225	1805
" 4-16-4	180	180	180	135	2518
Without lime					
Check	300	300	270	135	670
300 lbs. 0-16-0	120	120	180	135	1737
" 0-16-4	120	120	90	135	2207
" 4-16-0	120	180	180	90	2450
" 4-12-4	480	240	225	180	1499
" 4-16-4	120	180	225	135	2365

Table 16 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Berks silt loam
Location: - Virginia Agricultural Experiment Station Staunton

Crop: - Corn
Crop year : - 1941

Experiment: - Fertilizer rotation experiment with corn, wheat, and red clover, with and without lime.

Treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Without lime					
Check	40	40	80	30	30
400 lbs. 0-8-0	40	40	40	30	30
" 0-8-5	40	40	40	30	30
" 5-8-5	40	40	40	30	30
" 5-16-5	40	40	40	30	30
" 5-8-15	40	40	80	60	30
" 5-16-10	80	40	40	30	30
With lime					
Check	40	40	40	30	30
400 lbs. 0-8-0	40	40	40	30	30
" 0-8-5	160	40	40	30	30
" 5-8-5	40	40	40	30	30
" 5-16-5	40	40	40	30	30
" 5-8-15	280	40	160	60	30
" 5-16-10	160	40	120	30	30

Treatments	P_2O_5 extracted			
	Thornton	Morgan	Hester I	Hester II
Without lime				
Check	8	3	3	3
400 lbs. 0-8-0	8	3	8	8
" 0-8-5	24	8	8	8
" 5-8-5	8	8	8	8
" 5-16-5	8	48	16	16
" 5-8-15	8	8	8	8
" 5-16-10	8	8	8	8
With lime				
Check	3	3	3	3
400 lbs. 0-8-0	16	3	16	16
" 0-8-5	16	8	8	16
" 5-8-5	24	8	8	8
" 5-16-5	24	3	16	16
" 5-8-15	16	3	8	8

Table 16 - Staunton - Fertilizer rotation experiment - Corn - Cont'd.

Treatments	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Without lime				
Check	560	560	840	1260
400 lbs. 0-8-0	280	2240	2100	1680
" 0-8-5	1680	2240	2100	1680
" 5-8-5	560	560	840	1260
" 5-16-5	560	1120	840	1260
" 5-8-15	1120	1120	1260	1680
" 5-16-10	1120	1120	840	1260
With lime				
Check	1120	3360	2520	2940
400 lbs. 0-8-0	1120	1680	2520	1680
" 0-8-5	1680	1680	2520	2100
" 5-8-5	1680	3920	2100	1680
" 5-16-5	1680	1680	1680	1260
" 5-8-15	1680	2800	1680	1680
" 5-16-10	1680	3360	2100	1680

Treatments	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Without lime				
Check	120	120	90	135
400 lbs. 0-8-0	180	240	180	180
" 0-8-5	300	480	450	360
" 5-8-5	120	60	45	90
" 5-16-5	120	60	90	90
" 5-8-15	120	60	45	90
" 5-16-10	60	60	45	45
With lime				
Check	480	480	360	360
400 lbs. 0-8-0	480	480	360	360
" 0-8-5	360	480	450	360
" 5-8-5	360	480	360	360
" 5-16-5	360	360	360	360
" 5-8-15	360	600	270	360
" 5-16-10	360	480	360	360

Table 17 - Staunton - Fertilizer rotation experiment - Corn - Plant tissue tests and yield of corn in 1941.

Treatments		Yield Bu./A	7/8/41 NO_3	7/8/41 P_2O_5	7/8/41 K_2O	7/27/41 NO_3	7/27/41 P_2O_5	7/27/41 K_2O
Without lime								
Check		13.5	M	L	L	VL	M	VL
400 lbs.	0-8-0	15.6	L	L	VL	VL	H	VL
"	0-8-5	17.8	L	M	VL	VL	M	M
"	5-8-5	21.0	H	M	H	M	M	VL
"	5-16-5	23.0	VH	H	H	H	M	M
"	5-8-15	21.6	H	H	H	H	H	H
"	5-16-10	24.0	H	M	H	M	M	VH
With lime								
Check		17.1	M	VL	M	H	M	M
400 lbs.	0-8-0	25.4	M	L	M	M	H	VL
"	0-8-5	32.0	M	VL	M	H	H	M
"	5-8-5	34.0	H	H	H	H	H	VL
"	5-16-5	44.0	H	VH	H	H	H	VH
"	5-8-15	46.0	H	M	H	H	L	M
"	5-16-10	47.4	VH	VH	M	H	M	H

First tissue tests were made on July 8, when corn was only about 40 inches high. Second tests were made at the time corn was just beginning to silk and tassel.

Table 18 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of available soil nitrogen, based on organic matter content of soil.

Soil type: - Berks silt loam
Location: - Virginia Agricultural Experiment Station
Staunton

Crop: - Wheat
Crop year: - 1941

Experiment: - Fertilizer rotation experiment with corn, wheat, and red clover, with and without lime.

Treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Without lime					
Check	40	40	40	30	30
400 lbs. 0-8-0	40	40	40	30	30
" 0-8-5	40	40	40	30	30
" 5-8-5	40	40	40	30	30
" 5-16-5	40	40	40	30	30
" 5-8-15	40	40	40	30	30
" 5-16-10	80	40	40	30	30
With lime					
Check	40	40	40	30	30
400 lbs. 0-8-0	40	40	40	30	30
" 0-8-5	40	40	40	30	30
" 5-8-5	40	40	40	30	30
" 5-16-5	40	40	40	30	30
" 5-8-15	40	40	40	30	30
" 5-16-10	40	120	40	30	30

Treatments	P_2O_5 extracted			
	Thornton	Morgan	Hester I	Hester II
Without lime				
Check	0	0	3	0
400 lbs. 0-8-0	3	24	16	24
" 0-8-5	0	3	3	3
" 5-8-5	3	8	3	3
" 5-16-5	0	3	8	48
" 5-8-15	3	3	3	8
" 5-16-10	3	8	8	8
With lime				
Check	3	3	3	0
400 lbs. 0-8-0	3	32	8	8
" 0-8-5	0	8	8	3
" 5-8-5	3	8	8	3
" 5-16-5	24	32	3	8
" 5-8-15	3	8	8	3
" 5-16-10	8	3	3	8

Table 18 - Staunton - Fertilizer rotation experiment - Wheat - Cont'd.

Treatments	CaO extracted: Bray	Morgan	Hester I	Hester II	Organic Matter	Available Nitrogen *
	#/A	#/A	#/A	#/A	%	#/A
Without lime						
Check	560	1120	1260	840	1.84	46
400 lbs. 0-8-0	2800	1120	1260	2100	2.12	53
" 0-8-5	2800	2800	1260	2100	1.93	48
" 5-8-5	1120	1680	1260	840	1.98	50
" 5-16-5	560	2800	1680	840	2.02	51
" 5-8-15	1120	2800	1680	840	1.98	50
" 5-16-10	1680	2800	1260	1680	2.07	52
With lime						
Check	3920	1680	2100	2100	1.66	42
400 lbs. 0-8-0	3920	2800	2100	2100	2.16	54
" 0-8-5	3920	2800	2520	2520	1.88	47
" 5-8-5	3360	2240	2100	2100	1.79	45
" 5-16-5	3360	2800	2100	2100	1.88	47
" 5-8-15	3360	2800	2100	2100	2.10	53
" 5-16-10	3360	2800	2100	2100	1.98	50

Treatments	MgO extracted: Bray	Morgan	Hester I	Hester II	Yield Bu./A
Without lime					
Check	120	180	135	135	3.6
400 lbs. 0-8-0	180	300	180	135	7.6
" 0-8-5	180	240	180	135	9.2
" 5-8-5	60	60	90	45	9.8
" 5-16-5	30	60	45	45	12.6
" 5-8-15	60	60	45	45	11.3
" 5-16-10	60	60	45	45	13.0
With lime					
Check	180	360	450	360	5.1
400 lbs. 0-8-0	300	360	450	270	13.8
" 0-8-5	300	360	450	360	17.3
" 5-8-5	300	360	450	360	18.6
" 5-16-5	300	300	360	270	20.0
" 5-8-15	300	480	450	270	19.3
" 5-16-10	180	480	360	270	21.0

* Note: Nitrogen calculated as 5% of organic matter, with 2.5% nitrified annually (28).

Table 19 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Berks silt loam
Location: - Virginia Agricultural Experiment Station
Staunton

Crop: - Clover
Crop year: - 1941

Experiment: - Fertilizer rotation experiment with corn, wheat and red clover, with and without lime.

Residual fertilizer treatments	K_2O extracted: Bray	Thornton	Morgan	Hester I	Hester II
Without lime					
Check	80	40	40	30	30
400 lbs. 0-8-0	160	40	80	30	30
" 0-8-5	160	40	80	30	30
" 5-8-5	160	40	40	30	30
" 5-16-5	200	40	80	30	30
" 5-8-15	240	160	120	60	30
" 5-16-10	240	160	120	60	60
With lime					
Check	40	40	40	30	30
400 lbs. 0-8-0	80	40	160	30	30
" 0-8-5	40	40	40	30	30
" 5-8-5	80	40	120	60	60
" 5-16-5	80	40	40	30	30
" 5-8-15	160	40	160	60	60
" 5-16-10	160	40	160	60	60

Residual fertilizer treatments	P_2O_5 extracted: Thornton	Morgan	Hester I	Hester II
Without lime				
Check	3	32	3	3
400 lbs. 0-8-0	3	32	0	3
" 0-8-5	8	16	3	3
" 5-8-5	0	24	3	0
" 5-16-5	8	48	3	0
" 5-8-15	3	32	8	0
" 5-16-10	0	128	3	3
With lime				
Check	0	40	3	0
400 lbs. 0-8-0	0	32	8	12
" 0-8-5	0	80	3	3
" 5-8-5	3	80	8	8
" 5-16-5	3	64	8	12
" 5-8-15	3	48	0	0
" 5-16-10	8	80	3	0

Table 19 - Staunton - Fertilizer rotation experiment - Clover - Cont'd.

Residual fertilizer treatments	CaO extracted: Bray	Morgan	Hester I	Hester II
Without lime				
Check	560	1680	840	1260
400 lbs. 0-8-0	1680	1680	840	1260
" 0-8-5	1120	1680	840	840
" 5-8-5	1120	1120	1260	1260
" 5-16-5	1120	1120	840	840
" 5-8-15	560	1120	840	840
" 5-16-10	560	1120	840	840
With lime				
Check	1680	2800	2100	1680
400 lbs. 0-8-0	1680	2800	2100	2100
" 0-8-5	1680	2800	2100	2100
" 5-8-5	2240	3360	1680	2100
" 5-16-5	1680	2800	2100	2100
" 5-8-15	1680	2800	2100	2100
" 5-16-10	1680	2800	1680	2100

Residual fertilizer treatments	MgO extracted: Bray	Morgan	Hester I	Hester II	Yield hay Lbs./A.
Without lime					
Check	120	60	90	45	574
400 lbs. 0-8-0	180	120	90	90	852
" 0-8-5	120	60	45	45	996
" 5-8-5	60	60	45	45	900
" 5-16-5	60	60	45	45	1123
" 5-8-15	60	60	45	45	1090
" 5-16-10	120	60	45	45	1200
With lime					
Check	300	480	225	225	890
400 lbs. 0-8-0	300	480	225	360	1675
" 0-8-5	300	360	225	270	1836
" 5-8-5	300	360	270	225	1923
" 5-16-5	240	600	270	270	2064
" 5-8-15	300	600	360	270	1900
" 5-16-10	300	600	270	270	2160

Table 20 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Granville sandy loam
Location: - Virginia Agricultural Experiment Station Chatham

Crop: - Tobacco
Crop year: - 1941

Experiment: - Varying application rates of nitrogen, phosphoric acid and potash on bright tobacco.

Fertilizer treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Check	160	40	40	30	30
1000 lbs. 3-0-6	40	40	200	60	90
" 3-4-6	40	40	160	90	90
" 3-8-6	80	40	240	120	90
" 3-12-6	40	40	240	60	90
" 3-8-0	40	40	160	60	90
" 3-8-3	160	40	240	90	120
" 3-8-9	80	40	160	90	120
" 3-8-16	40	40	240	90	120

Fertilizer treatments	Tobacco		P_2O_5 extracted			
	lbs./A	$/A.	Morgan	Hester I	Hester II	Thornton
Check	192	23.60	0	3	0	32
1000 lbs. 3-0-6	454	65.60	8	8	3	8
" 3-4-6	1180	354.80	16	8	16	16
" 3-8-6	1264	379.00	48	48	48	128
" 3-12-6	1216	386.80	32	48	48	48
" 3-8-0	872	246.60	32	32	64	128
" 3-8-3	1148	361.00	32	48	64	96
" 3-8-9	1250	372.40	32	48	32	128
" 3-8-16	1294	392.40	64	64	64	128

Table 20 - Chatham - Tobacco - Cont'd.

Treatments	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	560	560	420	420
1000 lbs. 3-0-6	2240	2240	1260	1260
" 3-4-6	2240	2240	1260	1260
" 3-8-6	2240	2240	1260	1260
" 3-12-6	1120	1680	1260	1260
" 3-8-0	1120	1680	840	1260
" 3-8-3	1120	1680	840	840
" 3-8-9	1120	1680	840	840
" 3-8-16	1120	1680	840	840

Treatments	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	60	60	23	90
1000 lbs. 3-0-6	120	60	90	90
" 3-4-6	120	120	135	135
" 3-8-6	120	60	90	90
" 3-12-6	60	60	45	45
" 3-8-0	60	120	90	90
" 3-8-3	60	120	90	90
" 3-8-9	60	120	90	45
" 3-8-16	60	60	45	45

Table 21 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Granville sandy loam | Crop: - Tobacco
Location: - Virginia Agricultural Experiment Station Chatham | Crop year: - 1942

Experiment: - Varying application rates of nitrogen, phosphoric acid and potash on bright tobacco.

Fertilizer treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Check	160	40	80	60	60
1000 lbs. 3-0-6	160	40	80	60	60
" 3-4-6	200	40	160	60	60
" 3-8-6	240	40	40	60	60
" 3-12-6	160	40	200	30	60
" 3-8-0	80	40	40	30	30
" 3-8-3	40	40	40	30	60
" 3-8-9	40	40	40	60	60
" 3-8-16	160	40	160	60	60

Fertilizer treatments	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
Check	0	8	8	8
1000 lbs. 3-0-6	3	3	3	0
" 3-4-6	3	8	16	8
" 3-8-6	24	24	24	24
" 3-12-6	32	32	32	32
" 3-8-0	24	24	32	24
" 3-8-3	32	32	64	48
" 3-8-9	24	48	32	24
" 3-8-16	32	48	48	32

Table 21 - Chatham - Tobacco - Cont'd.

Treatments		Tobacco - 1942 lbs./A	$/A.	CaO extracted Bray	Morgan	Hester I	Hester II
Check		276	110.00	2240	2240	1260	1260
1000 lbs.	3-0-6	780	230.00	2240	2240	1260	1260
"	3-4-6	1224	507.20	2240	2240	1260	1260
"	3-8-6	1164	508.00	2240	2240	1260	1260
"	3-12-6	1140	513.20	2240	2240	1260	1260
"	3-8-0	998	423.40	2240	2240	1260	1260
"	3-8-3	1270	542.00	2240	2240	1260	1260
"	3-8-9	1246	539.20	2240	2240	1260	1260
"	3-8-16	1224	538.40	2240	2240	1260	1260

Treatments		MgO extracted Bray	Morgan	Hester I	Hester II
Check		30	60	45	22
1000 lbs.	3-0-6	60	120	135	90
"	3-4-6	120	120	135	90
"	3-8-6	60	60	90	90
"	3-12-6	60	120	135	90
"	3-8-0	60	60	90	90
"	3-8-3	60	120	90	90
"	3-8-9	60	120	90	90
"	3-8-16	60	60	90	90

Table 22 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Sassafras fine sandy loam Crop: - Corn
Location: - Virginia Agricultural Experiment Station Williamsburg Crop year: - 1941

Experiment: - Available Plant Food Experiment with corn and soybeans in a 2-year rotation receiving varying amounts of phosphoric acid and potash with the corn.

	K_2O extracted				
Fertilizer treatments	Bray	Thornton	Morgan	Hester I	Hester II
Check	400	160	400	300	270
500 lbs. 12-0-12	120	160	320	120	120
" 12-6-12	280	240	320	90	120
" 12-12-12	400	240	400	300	300
" 12-24-12	320	400	280	210	240
" 12-12-0	120	40	160	210	60
" 12-12-10	160	40	160	210	120
" 12-12-20	90	280	320	240	120
" 12-12-40	400	280	320	270	180

	P_2O_5 extracted			
Fertilizer treatments	Thornton	Morgan	Hester I	Hester II
Check	16	16	24	24
500 lbs. 12-0-12	3	16	3	0
" 12-6-12	3	8	8	8
" 12-12-12	80	48	32	24
" 12-24-12	24	32	48	24
" 12-12-0	16	24	8	8
" 12-12-10	32	8	16	24
" 12-12-20	3	16	8	3
" 12-12-40	0	8	16	8

Table 22 - Chatham - Tobacco - Cont'd.

Fertilizer treatments	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	1680	1680	1260	1260
500 lbs. 12-0-12	1680	1680	840	840
" 12-6-12	1680	1680	840	840
" 12-12-12	1680	1680	840	840
" 12-24-12	1680	1680	840	840
" 12-12-0	1680	1680	840	840
" 12-12-10	1680	1680	840	840
" 12-12-20	1680	1680	840	840
" 12-12-40	1680	1680	840	840

Fertilizer treatments	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	120	120	135	90
500 lbs. 12-0-12	60	60	90	45
" 12-6-12	60	60	45	45
" 12-12-12	120	120	90	90
" 12-24-12	30	30	22	22
" 12-12-0	30	30	45	22
" 12-12-10	120	120	135	90
" 12-12-20	30	120	22	22
" 12-12-40	60	30	45	45

Table 23 - Williamsburg - Corn - Cont'd - Plant tissue tests and yields of corn in 1941.

Fertilizer treatments	Yield: Bu./A.	7/25/41 NO_3	7/25/41 P_2O_5	7/25/41 K_2O	8/17/41 NO_3	8/17/41 P_2O_5	8/17/41 K_2O
Check	58.5	H	M	VL	VL	H	VL
500 lbs. 12-0-12	55.1	H	VL	H	M	H	M
" 12-6-12	60.5	M	M	H	L	H	H
" 12-12-12	69.4	VL	M	H	VL	H	H
" 12-24-12	66.8	H	VL	VL	M	M	M
" 12-12-0	66.0	H	H	H	M	H	M
" 12-12-10	66.2	M	M	VL	H	H	VH
" 12-12-20	63.7	H	H	VL	H	H	H
" 12-12-40	65.4	H	H	H	H	H	VH

Remarks: - Fertilizer applied broadcast and disked into the soil before corn was planted.

Tissue test on July 25 were made when corn was only about 30 inches tall. Second tests were made when corn was beginning to tassel and silk.

Magnesium deficiency became very severe toward the latter part of August and early September.

Table 24 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Sassafras fine sandy loam
Location: - Virginia Agricultural Experiment Station
Williamsburg

Crop: - Soybeans
Crop year: - 1941

Experiment: - Available Plant Food Experiment with corn and soybeans in a 2-year rotation receiving varying amounts of phosphoric acid and potash with the corn.

Residual Fertilizer treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Check	320	80	40	210	150
500 lbs. 12-0-12	360	40	40	270	180
" 12-6-12	400	40	40	240	180
" 12-12-12	280	40	40	210	210
" 12-24-12	400	40	120	180	180
" 12-12-0	240	40	40	120	120
" 12-12-10	400	80	200	210	150
" 12-12-20	360	40	160	210	150
" 12-12-40	400	160	320	210	150

Residual Fertilizer treatments	P_2O_5 extracted			
	Thornton	Morgan	Hester I	Hester II
Check	3	24	24	3
500 lbs. 12-0-12	3	8	8	8
" 12-6-12	32	16	16	16
" 12-12-12	80	16	16	24
" 12-24-12	96	24	24	32
" 12-12-0	32	16	16	16
" 12-12-10	64	16	16	24
" 12-12-20	48	24	24	16
" 12-12-40	48	24	24	8

Table 24 - Williamsburg - Soybeans - Cont'd.

Residual Fertilizer treatments	CaO extracted Bray	Morgan	Hester I	Hester II
Check	2240	2240	1260	1260
500 lbs. 12-0-12	2240	2240	840	840
" 12-6-12	2240	2240	840	840
" 12-12-12	2240	2800	1680	840
" 12-24-12	2240	2240	840	840
" 12-12-0	2240	2800	1680	1260
" 12-12-10	2240	2240	840	840
" 12-12-20	2240	2240	840	840
" 12-12-40	2240	2240	840	840

Residual Fertilizer treatments	MgO extracted Bray	Morgan	Hester I	Hester II	Hay Lbs./A
Check	60	30	135	135	3080
500 lbs. 12-0-12	30	30	45	45	4720
" 12-6-12	30	30	45	45	4620
" 12-12-12	30	60	45	22	4600
" 12-24-12	60	30	45	45	4520
" 12-12-0	60	30	90	45	4000
" 12-12-10	30	30	45	22	4280
" 12-12-20	60	30	45	22	4600
" 12-12-40	60	30	22	22	4640

Magnesium deficiency was evident throughout all treatments at time of harve sting for hay.

Table 25 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Onslow fine sandy loam
Location: - Virginia Agricultural Experiment Station
Holland

Crop: - Corn
Crop year: - 1941

Experiment: - Rates of liming for corn, cotton and peanuts

Lime treatments		P_2O_5 extracted			
	Bu./A	Morgan	Hester I	Hester II	Thornton
None	71.4	24	32	24	80
600 lbs. oyster shell	71.9	48	80	80	128
900 lbs. " "	82.1	32	32	32	128
1200 lbs. " "	83.6	48	32	64	32
1500 lbs. " "	87.1	36	32	64	24
1800 lbs. " "	72.1	24	64	48	128
2100 lbs. " "	60.7	48	24	48	128
2400 lbs. " "	41.4	48	64	96	64
2700 lbs. " "	35.7	48	48	64	64
3000 lbs. " "	53.6	48	48	80	128

Lime treatments	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
None	160	40	120	30	30
600 lbs. oyster shell	160	40	120	30	30
900 lbs. " "	160	40	160	30	30
1200 lbs. " "	80	40	200	30	30
1500 lbs. " "	120	40	120	30	30
1800 lbs. " "	160	40	160	30	30
2100 lbs. " "	160	40	160	30	90
2400 lbs. " "	160	40	120	60	90
2700 lbs. " "	160	40	80	30	60
3000 lbs. " "	160	40	160	30	60

Table 25 - Holland - Corn - Cont'd.

Lime treatments	CaO extracted Bray	Morgan	Hester I	Hester II
None	1680	1120	840	1260
600 lbs. oyster shell	1120	1120	840	1260
900 lbs. " "	1120	2800	840	1260
1200 lbs. " "	1680	2800	840	1680
1500 lbs. " "	1120	2240	1260	1680
1800 lbs. " "	1120	2800	1680	1260
2100 lbs. " "	1120	2800	1680	1260
2400 lbs. " "	1120	2800	1680	1680
2700 lbs. " "	1120	1680	1680	1680
3000 lbs. " "	1680	2240	1680	1260

Lime treatments	MgO extracted Bray	Morgan	Hester I	Hester II
None	30	30	22	22
600 lbs. oyster shell	60	30	45	22
900 lbs. " "	60	60	90	45
1200 lbs. " "	120	180	90	90
1500 lbs. " "	180	180	180	135
1800 lbs. " "	240	300	225	180
2100 lbs. " "	240	300	270	225
2400 lbs. " "	240	300	270	270
2700 lbs. " "	240	360	360	360
3000 lbs. " "	300	480	360	360

Table 26 - Pounds per acre of K20, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Onslow fine sandy loam
Location: - Virginia Agricultural Experiment Station Holland

Crop: - Cotton
Crop year: - 1941

Experiment: - Rates of liming for corn, cotton and peanuts.

Lime treatments	Cotton: Lbs./A	P2O5 extracted: Morgan	Hester I	Hester II	Thornton
None	1100	80	48	80	128
600 lbs. oyster shell	1165	80	48	64	80
900 lbs. " "	960	64	24	48	48
1200 lbs. " "	1275	64	48	48	128
1500 lbs. " "	1135	32	32	32	80
1800 lbs. " "	1285	48	96	80	128
2100 lbs. " "	785	32	32	24	128
2400 lbs. " "	425	80	48	32	128
2700 lbs. " "	650	64	32	48	96
3000 lbs. " "	1100	48	48	64	128

Lime treatments	K2O extracted: Bray	Thornton	Morgan	Hester I	Hester II
None	200	40	240	120	120
600 lbs. oyster shell	160	40	40	90	60
900 lbs. " "	200	40	40	90	120
1200 lbs. " "	240	40	80	120	120
1500 lbs. " "	200	40	200	60	120
1800 lbs. " "	200	40	80	120	120
2100 lbs. " "	200	40	240	90	90
2400 lbs. " "	240	40	200	90	120
2700 lbs. " "	200	40	200	90	120
3000 lbs. " "	200	40	200	120	90

Table 26 - Holland - Cotton - Cont'd.

Lime treatments	CaO extracted: Bray	Morgan	Hester I	Hester II
None	1680	1680	1260	1680
600 lbs. oyster shell	2240	2240	1680	1260
900 lbs. " "	1680	2240	1260	1260
1200 lbs. " "	1680	2240	1260	1260
1500 lbs. " "	2240	1680	1260	1680
1800 lbs. " "	1680	2240	1680	1260
2100 lbs. " "	1680	2240	1260	1260
2400 lbs. " "	1680	2800	1260	2100
2700 lbs. " "	1680	2800	2100	1680
3000 lbs. " "	2240	2800	1680	1680

Lime treatments	MgO extracted: Bray	Morgan	Hester I	Hester II
None	30	60	22	45
600 lbs. oyster shell	60	120	22	90
900 lbs. " "	30	60	45	45
1200 lbs. " "	60	60	45	45
1500 lbs. " "	120	120	90	90
1800 lbs. " "	120	120	90	90
2100 lbs. " "	120	180	90	135
2400 lbs. " "	240	240	180	225
2700 lbs. " "	180	240	225	180
3000 lbs. " "	180	300	180	180

Table 27 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions.

Soil type: - Onslow fine sandy loam — Crop: - Peanuts
Location: - Virginia Agricultural Experiment Station Holland — Crop year: - 1941

Experiment: - Rates of liming for corn, cotton and peanuts.

Lime treatments	Peanuts Lbs./A.	P_2O_5 extracted Morgan	Hester I	Hester II	Thornton
None	925	32	32	48	48
600 lbs. oyster shell	1175	24	48	48	96
900 lbs. " "	1225	24	64	48	32
1200 lbs. " "	1425	16	48	64	48
1500 lbs. " "	1725	32	48	80	64
1800 lbs. " "	1500	48	48	64	48
2100 lbs. " "	1275	48	64	96	128
2400 lbs. " "	925	48	48	64	128
2700 lbs. " "	775	48	32	48	96
3000 lbs. " "	1000	32	64	48	64

Lime treatments	K_2O extracted Bray	Thornton	Morgan	Hester I	Hester II
None	40	40	40	90	90
600 lbs. oyster shell	80	40	40	90	90
900 lbs. " "	160	40	160	120	150
1200 lbs. " "	200	40	40	90	120
1500 lbs. " "	160	40	120	120	120
1800 lbs. " "	120	40	40	90	90
2100 lbs. " "	160	40	160	120	120
2400 lbs. " "	120	40	200	120	120
2700 lbs. " "	200	40	160	120	120
3000 lbs. " "	200	40	120	120	150

Table 27 - Holland - Peanuts - Cont'd.

Lime treatments	CaO extracted			
	Bray	Morgan	Hester I	Hester II
None	1680	1120	840	840
600 lbs. oyster shell	1680	1680	840	1260
900 lbs. " "	1680	1680	1260	1680
1200 lbs. " "	1680	1680	1260	1680
1500 lbs. " "	1680	2240	1680	1680
1800 lbs. " "	1680	1680	1680	1680
2100 lbs. " "	2240	2240	1680	1680
2400 lbs. " "	2800	2240	1680	1680
2700 lbs. " "	2800	2800	1680	1680
3000 lbs. " "	1680	2800	1680	1680

Lime treatments	MgO extracted			
	Bray	Morgan	Hester I	Hester II
None	30	30	22	45
600 lbs. oyster shell	60	30	45	90
900 lbs. " "	60	60	90	90
1200 lbs, " "	120	60	90	135
1500 lbs. " "	120	180	180	135
1800 lbs. " "	180	180	225	180
2100 lbs. " "	180	180	225	225
2400 lbs. " "	180	240	225	180
2700 lbs. " "	240	300	360	360
3000 lbs. " "	240	300	360	360

B. CURRENT FERTILIZER TREATMENTS

Before rapid soil tests can be satisfactorily used as a basis for fertilizer recommendations on a given soil or group of similar soils, the test for each nutrient must be calibrated in terms of crop response to known applications of the nutrient. To do this it is necessary to determine response for each crop at varying levels of the nutrient in the soil. A separate controlled experiment involving a sequence of incremental applications of the nutrient must be conducted at each of several soil levels of the element. The levels selected for this purpose should cover the entire range of soil supplies of the nutrient normally found in the soil (or group of similar soils) for which the calibration is being made.

In the spring of 1941, a series of six experiments with corn, five experiments with peanuts, and two with cotton were laid out on farms in the Coastal Plains soil province in Southeastern Virginia. At each location five plots received equal amounts of potash while the phosphate treatment was varied. Five additional plots received uniform phosphate applications with varying rates of potash. These plots received uniform nitrogen applications, except in the experiments with peanuts, where no nitrogen was used. Corn check plots received only the 200# side-dressing of sodium nitrate which was applied to all plots when the corn was knee high. With the other crops, check plots received no fertilizer. Each treatment was duplicated at each location.

Five experiments with corn were put out on farms in the Shenandoah

Valley in the vicinity of Brownsburg. The design of these plots was similar to those in Southeastern Virginia, except that a higher initial nitrogen application was used and no supplemental side-dressing was made.

During 1941, another group of experiments was established in the neighborhood of Staunton by the VPI Agronomy Department to compare variable phosphate and potash applications with phosphate-balanced manure. These experiments were not planned primarily to assist in calibrating soil tests. However, the variable phosphate and potash treatments made them well adapted to such a calibration. Included in this group of experiments were five with corn, six with wheat, and one with barley. A single series of treatments without replicates was used at each location.

A representative soil sample was taken from each experimental area in the spring. Plant tissue tests of all crops except wheat and barley were made twice during the growing season. The data pertaining to these experiments are presented in Tables 28 through 87.

Table 28 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Onslow fine sandy loam
Location: - Joe Collins
Whaleyville

Crop: - Corn
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted					
	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	80	20	80	30	30	200
None	80	20	80	30	30	200
Average	80	20	80	30	30	200

Treatment	P_2O_5 extracted				
	Morgan	Hester I	Hester II	Thornton	Purvis
None	16	8	16	48	48
None	24	8	16	32	48
Average	20	8	16	40	48

Treatment	CaO extracted				
	Bray	Morgan	Hester I	Hester II	pH
None	140	280	210	210	5.6
None	280	280	210	210	5.4
Average	210	280	210	210	5.5

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester II
None	10	10	25	25
None	10	10	8	25
Average	10	10	16	25

Table 29 - Joe Collins - Cont'd. - Yield of corn per acre and plant tissue tests. Averages of duplicate treatments and tissue tests.

Fertilizer Treatments	Total Yield: Bus/A	Tissue Tests 7/10/41 NO_3	P_2O_5	K_2O	Tissue Tests 8/5/41 NO_3	P_2O_5	K_2O
300 lbs. 2-0-6	33.7	M	M	M	VL	L	L
2-6-6	38.3	M	M	M	VL	M	M
2-12-6	37.6	M	M	M	VL	M	L
2-18-6	36.3	M	M	H	VL	M	M
2-24-6	35.9	L	M	M	VL	H	M
Check	30.0	L	M	L	VL	L	L
2-12-0	30.7	L	M	L	VL	L	L
2-12-12	38.5	H	M	VH	VL	L	M
2-12-18	38.6	H	M	VH	VL	L	L
2-12-24	37.6	H	M	VH	VL	M	M

Remarks: - Fertilizer applied in row at time of planting. No deficiency symptoms were observed on July 10 at time first tissue tests were made. However, on August 5, the time of second testing, all plots showed nitrogen deficiency. Corn topdressed, when knee high, with 200 lbs. of nitrate of soda per acre.

First tissue tests were made at the time corn was beginning to silk and tassel. Second tests were made when the corn was in the early dough stage.

Table 30 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Norfolk fine sandy loam
Location: - Thomas Roundtree
Whaleyville

Crop: - Corn
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted					
	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	120	80	120	90	60	120
None	80	40	80	60	60	120
Average	100	60	100	75	60	120

Treatment	P_2O_5 extracted				
	Morgan	Hester I	Hester II	Thornton	Purvis
None	16	32	24	80	60
None	24	16	16	48	60
Average	20	24	20	64	60

Treatment	CaO extracted				
	Bray	Morgan	Hester I	Hester II	pH
None	280	560	210	210	6.0
None	280	560	210	210	6.0
Average	280	560	210	210	6.0

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester II
None	10	10	7	7
None	10	10	7	7
Average	10	10	7	7

Table 31 - Roundtree - Cont'd. - Yield of corn per acre, and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer Treatments	Total Yield: Bus./A	7/10/41 NO_3	7/10/41 P_2O_5	7/10/41 K_2O	8/6/41 NO_3	8/6/41 P_2O_5	8/6/41 K_2O
300 lbs. 2-0-6	34.2	H	M	M	M	M	L
2-6-6	39.1	H	M	M	L	M	L
2-12-6	38.8	H	M	M	L	M	M
2-18-6	38.2	H	M	M	M	M	M
2-24-6	37.3	H	M	M	L	M	L
Check	29.8	M	M	M	M	L	VL
2-12-0	31.7	H	M	L	L	M	L
2-12-12	39.4	H	M	M	M	H	M
2-12-18	39.2	H	M	H	M	H	L
2-12-24	38.7	H	M	H	M	M	M

Remarks: - Fertilizer applied in row at time of planting. Corn top-dressed with 200 lbs. of nitrate of soda per acre, when knee high.

Magnesium deficiency noted on all plots on July 10, and on August 6 it was very marked.

First tissue tests were made at the time the corn was just beginning to silk and tassel. Second tests were made when the corn was in the early dough stage.

Table 32. - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Lenoir fine sandy loam　　　　Crop: - Corn
Location: - Wallace Winslow　　　　Crop year: - 1941
Suffolk

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted					
	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	160	120	120	60	60	200
None	160	80	120	60	60	200
Average	160	100	120	60	60	200

Treatment	P_2O_5 extracted				
	Morgan	Hester I	Hester II	Thornton	Purvis
None	16	3	16	64	62
None	16	3	16	64	62
Average	16	3	16	64	62

Treatment	CaO extracted				
	Bray	Morgan	Hester I	Hester II	pH
None	280	1120	840	420	6.4
None	280	1120	1260	420	6.3
Average	280	1120	1050	420	6.35

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester II
None	133	133	150	150
None	133	199	150	150
Average	133	166	150	150

Table 33 - Winslow - Cont'd - Yield of corn per acre, and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer Treatments		Total Yield: Bus./A	7/8/41 NO3	P2O5	K2O	8/4/41 NO3	P2O5	K2O
300 lbs.	2-0-6	31.7	H	M	L	VL	H	H
	2-6-6	32.2	H	M	L	VL	H	H
	2-12-6	37.6	H	H	M	M	M	L
	2-18-6	38.1	H	H	L	M	H	H
	2-24-6	43.0	H	M	M	M	H	M
	Check	30.8	L	H	L	L	H	L
	2-12-0	37.3	H	H	L	M	M	VL
	2-12-12	39.4	VH	M	M	H	H	M
	2-12-18	33.1	VH	M	H	VL	M	M
	2-12-24	34.9	VH	H	H	H	VH	H

Remarks: - Fertilizer applied in row at planting. Corn top-dressed with 200 lbs. nitrate of soda when knee high.

First tissue tests were made at the time the corn began to silk and tassel. Second tests were made when corn was in the early dough stage.

Table 34 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Onslow very fine sandy loam — Crop: - Corn
Location: - Sam Turner, Suffolk — Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

	K_2O extracted					
Treatment	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	120	80	80	60	60	160
None	120	80	80	60	60	200
Average	120	80	80	60	60	180

	P_2O_5 extracted				
Treatment	Morgan	Hester I	Hester II	Thornton	Purvis
None	8	3	32	64	60
None	8	3	32	64	62
Average	8	3	32	64	61

	CaO extracted				
Treatment	Bray	Morgan	Hester I	Hester II	pH
None	560	560	420	420	5.8
None	560	560	420	420	6.0
Average	560	560	420	420	5.9

	MgO extracted			
Treatment	Bray	Morgan	Hester I	Hester II
None	66	66	50	50
None	66	66	50	50
Average	66	66	50	50

Table 35 - Sam Turner - Cont'd. - Yield of corn per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments		Yield Bu./A	7/9/41 NO3	7/9/41 P_2O_5	7/9/41 K_2O	8/4/41 NO3	8/4/41 P_2O_5	8/4/41 K_2O
300 lbs.	2-0-6	42.2	H	H	H	H	H	L
	2-6-6	46.7	H	H	Y	H	H	L
	2-12-6	45.8	H	H	H	M	H	L
	2-18-6	44.7	H	H	H	H	H	L
	2-24-6	43.8	H	H	H	M	L	M
	Check	41.5	L	M	M	M	H	VL
	2-12-0	42.9	M	H	L	L	M	L
	2-12-12	42.2	M	H	M	L	L	L
	2-12-18	46.9	H	H	H	H	H	M
	2-12-24	41.3	H	H	H	L	M	L

Remarks: - Fertilizer was applied in the row at planting. Corn was top-dressed with 200 lbs. of nitrate of soda when knee high.

Soybeans were planted in the corn. During late July and August a dry spell occured which probably cut down the yield of corn.

First tissue tests were made at the time corn began to silk and tassel. Second tests were made when corn was in the early dough stage.

Table 36 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Norfolk fine sandy loam
Location: - Marriot Davis
Whaleyville

Crop: - Corn
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

	K_2O extracted					
Treatment	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	80	80	80	60	60	120
None	120	80	80	60	30	120
Average	100	80	80	60	45	120

	P_2O_5 extracted				
Treatment	Morgan	Hester I	Hester II	Thornton	Purvis
None	16	16	48	96	48
None	16	32	48	128	48
Average	16	24	48	112	48

	CaO extracted				
Treatment	Bray	Morgan	Hester I	Hester II	pH
None	280	280	210	420	5.8
None	280	280	210	420	6.0
Average	280	280	210	420	5.9

	MgO extracted			
Treatment	Bray	Morgan	Hester I	Hester II
None	33	33	50	50
None	33	33	50	50
Average	33	33	50	50

Table 37 - Marriot Davis - Cont'd. - Yield of corn per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments		Yield Bu./A	NO_3	P_2O_5	K_2O	8/6/41 NO_3	8/6/41 P_2O_5	8/6/41 K_2O
300 lbs.	2-0-6	55.0				L	H	H
	2-6-6	52.1				L	M	L
	2-12-6	60.6				L	H	M
	2-18-6	62.1	No tests made			VL	H	M
	2-24-6	64.0	made in July -			M	H	H
	Check	46.9	rained out			L	VH	L
	2-12-0	61.9				M	VH	M
	2-12-12	66.4				VL	H	M
	2-12-18	62.2				VL	H	M
	2-12-24	56.1				L	H	H

Remarks: - Fertilizer was applied in the row at planting. Corn was top-dressed with 200 lbs. per acre of nitrate of soda when knee high.

Plant tissue tests were made when the corn was in the early dough stage.

Table 38 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Norfolk sandy loam
Location: - B. Blythe
Franklin

Crop: - Corn
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

	K_2O extracted					
Treatment	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	80	40	80	60	15	160
None	120	120	120	120	60	160
Average	100	80	100	90	37	160

	P_2O_5 extracted				
Treatment	Morgan	Hester I	Hester II	Thornton	Purvis
None	16	16	24	112	48
None	16	16	16	80	60
Average	16	16	20	96	54

	CaO extracted				
Treatment	Bray	Morgan	Hester I	Hester II	pH
None	560	560	420	420	6.2
None	560	560	420	420	5.9
Average	560	560	420	420	6.15

	MgO extracted			
Treatment	Bray	Morgan	Hester I	Hester II
None	10	10	25	7
None	10	33	25	7
Average	10	22	25	7

Table 39 - B. Blythe - Cont'd. - Yield of corn in bushels per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments		Yield Bu./A	NO_3	P_2O_5	K_2O	8/1/41 NO_3	8/1/41 P_2O_5	8/1/41 K_2O
300 lbs.	2-0-6	39.0				VL	M	M
	2-6-6	39.7				VL	M	H
	2-12-6	45.1				VL	H	M
	2-18-6	39.3	No test made			L	VH	H
	2-24-6	40.3	in July			L	VH	L
	Check	33.9				M	VH	L
	2-12-0	53.1				L	L	L
	2-12-12	55.6				M	H	VH
	2-12-18	55.6				H	VH	H
	2-12-24	50.6				L	VH	H

Remarks: - Fertilizer applied in the row at planting. Corn was top-dressed with 200 pounds of nitrate of soda per acre when knee high. Very marked magnesium deficiency noted on August 1. Slight nitrogen deficiency noted also.

Plant tissue tests were made when corn was in the early dough stage.

Table 40 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Norfolk fine sandy loam
Location: - Thomas Roundtree
Whaleyville

Crop: - Cotton
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

	K_2O extracted					
Treatment	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	160	80	120	120	120	120
None	160	120	120	120	150	80
Average	160	100	120	120	135	100

	P_2O_5 extracted				
Treatment	Morgan	Hester I	Hester II	Thornton	Purvis
None	8	16	16	8	40
None	8	8	16	8	40
Average	8	12	16	8	40

	CaO extracted				
Treatment	Bray	Morgan	Hester I	Hester II	pH
None	280	1120	1260	1260	6.0
None	280	560	840	840	5.9
Average	280	890	1150	1150	5.95

	MgO extracted			
Treatment	Bray	Morgan	Hester I	Hester II
None	66	66	50	50
None	66	33	50	50
Average	66	50	50	50

Table 41 - Roundtree - Cont'd. - Yield of seed cotton per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments		Yield Lbs./A	7/10/41 NO_3	7/10/41 P_2O_5	7/10/41 K_2O	8/6/41 NO_3	8/6/41 P_2O_5	8/6/41 K_2O
500 lbs.	4-0-6	1570	H	H	VH	L	H	L
	4-5-6	1840	H	M	H	L	M	M
	4-10-6	2110	H	H	H	L	H	L
	4-15-6	2080	H	H	H	L	H	L
	4-20-6	2090	H	M	H	VL	H	M
	Check	1020	H	M	VH	VL	H	L
	4-10-0	1720	H	H	H	VL	H	L
	4-10-12	2280	H	M	H	VL	H	M
	4-10-18	2310	H	M	H	VL	H	M
	4-10-24	2300	H	H	H	L	H	M

Remarks: - Fertilizer was applied in the row, bedded on, and cotton planted by local method. Magnesium deficiency was beginning to show on August 6 on plots receiving heavy applications of potash.

First tissue tests were made when cotton was about 20 inches high. Second tests were made when it was in full bloom.

Table 42 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Norfolk fine sandy loam
Location: - Leland Beale
Franklin

Crop: - Cotton
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted					
	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	160	120	120	90	90	120
None	80	40	40	30	30	160
Average	120	80	80	60	60	140

Treatment	P_2O_5 extracted				
	Morgan	Hester I	Hester II	Thornton	Purvis
None	24	16	24	96	56
None	16	8	8	48	60
Average	20	12	16	72	58

Treatment	CaO extracted				
	Bray	Morgan	Hester I	Hester II	pH
None	560	560	420	420	5.8
None	280	280	420	420	5.7
Average	420	420	420	420	5.75

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester II
None	66	66	50	50
None	33	33	25	50
Average	50	50	38	50

Table 43 - Leland Beale - Cont'd. - Yield of seed cotton in pounds per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments	Yield Lbs./A	NO_3	P_2O_5	K_2O	8/2/41 NO_3	8/2/41 P_2O_5	8/2/41 K_2O
500 lbs. 4-0-6	2330				L	M	L
4-5-6	2480				VL	H	H
4-10-6	2440				M	H	H
4-15-6	2450	No tests were			M	H	H
4-20-6	2550	made in July			M	H	L
Check	1720				M	VH	M
4-10-0	2400				L	H	M
4-10-12	2600				L	H	L
4-10-18	2370				L	H	M
4-10-24	2430				L	H	H

Remarks: - Fertilizer was applied in the row, bedded on, and cotton planted by local method.

Plant tissue tests were made when cotton was in full bloom.

Table 44 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Norfolk fine sandy loam
Location: - Sam Turner
Suffolk

Crop: - Peanuts
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

	K_2O extracted					
Treatment	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	120	80	80	90	90	160
None	120	80	80	120	120	120
Average	120	80	80	105	105	140

	P_2O_5 extracted				
Treatment	Morgan	Hester I	Hester II	Thornton	Purvis
None	16	16	16	8	16
None	24	32	32	16	8
Average	20	24	24	12	12

	CaO extracted				
Treatment	Bray	Morgan	Hester I	Hester II	pH
None	280	560	840	840	5.8
None	280	1120	1260	1260	6.4
Average	280	840	1050	1050	6.2

	MgO extracted			
Treatment	Bray	Morgan	Hester I	Hester II
None	66	66	100	150
None	133	133	100	150
Average	100	100	100	150

Table 45 - Sam Turner - Cont'd. - Yield of peanuts per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments		Yield Lbs./A	7/8/41 NO3	P2O5	K2O	8/4/41 NO3	P2O5	K2O
400 lbs.	0-0-12	1685	-	M	H	-	M	H
	0-6-12	1685	-	L	H	-	M	H
	0-12-12	2030	-	M	H	-	M	L
	0-18-12	1855	-	M	H	-	M	M
	0-24-12	2120	-	M	H	-	M	M
	Check	1610	-	M	H	-	H	L
	0-12-0	2040	-	L	H	-	H	VL
	0-12-6	2110	-	L	H	-	H	M
	0-12-18	1850	-	M	H	-	H	M
	0-12-24	1920	-	L	H	-	H	H

Remarks: - Fertilizer was applied in the row and bedded on at planting. Fertilizer contained dolomitic limestone equivalent to 400 lbs. per ton.

First tissue tests were made when plants were about 15 inches in diameter. Second tests were made when they were about 24 inches in diameter.

Table 46 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O, and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Onslow fine sandy loam
Location: - Joe Collins
Whaleyville

Crop: - Peanuts
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted					
	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	80	40	40	60	30	160
None	80	80	80	60	60	120
Average	80	60	60	60	45	140

Treatment	P_2O_5 extracted				
	Morgan	Hester I	Hester II	Thornton	Purvis
None	16	16	8	24	60
None	16	16	8	24	60
Average	16	16	8	24	60

Treatment	CaO extracted				
	Bray	Morgan	Hester I	Hester II	pH
None	280	280	420	420	5.3
None	280	280	420	210	5.5
Average	280	280	420	315	5.4

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester II
None	33	33	25	25
None	33	10	8	25
Average	33	21	17	25

Table 47 - Joe Collins - Cont'd. - Yield of peanuts in pounds per acre and plant tissue tests. Averages of duplicate treatments and tests.

Fertilizer treatments	Total Yield: Lbs./A	7/10/41 NO_3	7/10/41 P_2O_5	7/10/41 K_2O	8/5/41 NO_3	8/5/41 P_2O_5	8/5/41 K_2O
400 lbs. 0-0-12	1940	-	M	H	-	H	VH
0-6-12	2210	-	M	VH	-	H	VH
0-12-12	1830	-	M	H	-	M	M
0-18-12	1540	-	H	H	-	H	H
0-24-12	1620	-	VL	H	-	H	M
Check	1350	-	VL	H	-	H	VL
0-12-0	1670	-	M	H	-	M	L
0-12-6	1800	-	M	H	-	H	M
0-12-18	2280	-	M	H	-	H	M
0-12-24	1870	-	M	H	-	H	L

Remarks: - Fertilizer applied in row and bedded on at planting. Fertilizer contained dolomitic limestone equivalent to 400 pounds per ton.

Plants were about 15 inches in diameter at time first tests were made, and about 24 inches in diameter at second testing.

Table 48 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Norfolk fine sand
Location: - Thomas Roundtree
Whaleyville

Crop: - Peanuts
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted					
	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	80	40	80	90	90	120
None	80	40	80	90	90	120
Average	80	40	80	90	90	120

Treatment	P_2O_5 extracted				
	Morgan	Hester I	Hester II	Thornton	Purvis
None	8	8	16	8	40
None	8	16	16	16	32
Average	8	12	16	12	36

Treatment	CaO extracted				
	Bray	Morgan	Hester I	Hester II	pH
None	140	560	420	840	5.2
None	280	560	840	840	5.9
Average	210	560	630	840	5.6

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester II
None	66	33	50	100
None	66	33	50	100
Average	66	33	50	100

Table 49 - Roundtree - Cont'd. - Yield of peanuts in pounds per acre, and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments	Yield Lbs./A	7/10/41 NO_3	7/10/41 P_2O_5	7/10/41 K_2O	8/6/41 NO_3	8/6/41 P_2O_5	8/6/41 K_2O
400 lbs. 0-0-12	1670	-	VL	VH	-	M	M
0-6-12	1760	-	VL	VH	-	M	M
0-12-12	2040	-	VL	VH	-	L	M
0-18-12	1860	-	VL	VH	-	L	M
0-24-12	1970	-	L	VH	-	L	M
Check	1410	-	VL	H	-	M	M
0-12-0	1990	-	L	H	-	M	L
0-12-6	2240	-	M	H	-	M	M
0-12-18	1930	-	L	H	-	L	M
0-12-24	2020	-	M	H	-	M	M

Remarks: - Fertilizer applied in row and bedded on at planting. Fertilizer contained dolomitic limestone equivalent to 400 pounds per acre.

First tissue tests were made when the plants were about 15 inches in diameter and the second tests were made when they were about 24 inches in diameter.

Table 50 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solution containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Norfolk fine sandy loam
Location: - Marriott Davis
Whaleyville

Crop: - Peanuts
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

	K_2O extracted					
Treatment	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	120	80	80	60	60	160
None	120	120	80	90	90	120
Average	120	100	80	75	75	140

	P_2O_5 extracted				
Treatment	Morgan	Hester I	Hester II	Thornton	Purvis
None	32	64	64	128	32
None	32	64	48	128	32
Average	32	64	56	128	32

	CaO extracted				
Treatment	Bray	Morgan	Hester I	Hester II	pH
None	560	280	420	420	6.0
None	280	280	210	420	5.8
Average	420	280	315	420	5.9

	MgO extracted			
Treatment	Bray	Morgan	Hester I	Hester II
None	33	33	50	50
None	66	33	25	50
Average	50	33	38	50

Table 51 - Marriott Davis - Cont'd. Yield of peanuts per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments		Yield Lbs./A	NO_3	P_2O_5	K_2O	8/6/41 NO_3	8/6/41 P_2O_5	8/6/41 K_2O
400 lbs.	0-0-12	1360				-	M	M
	0-6-12	1460				-	M	M
	0-12-12	1420				-	M	M
	0-18-12	1680	No tissue tests			-	M	M
	0-24-12	1600	were made in			-	H	M
	Check	920	July -			-	M	M
	0-12-0	1420	rained out			-	M	M
	0-12-6	1620				-	M	M
	0-12-18	1465				-	M	M
	0-12-24	1465				-	M	M

Remarks: - Fertilizer was applied in the row and bedded on at planting. Fertilizer contained dolomitic limestone equivalent to 400 pounds per ton.

Plants were about 24 inches in diameter when tissue tests were made.

Table 52 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from modified Purvis' absorption solutions containing the equivalent of 400 pounds per acre of K_2O and 64 pounds per acre of P_2O_5 in the original solution.

Soil type: - Norfolk sandy loam
Location: - Harvey Darden
Franklin

Crop: - Peanuts
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

	K_2O extracted					
Treatment	Bray	Thornton	Morgan	Hester I	Hester II	Purvis
None	200	160	160	150	150	160
None	200	160	160	150	150	160
Average	200	160	160	150	150	160

	P_2O_5 extracted				
Treatment	Morgan	Hester I	Hester II	Thornton	Purvis
None	32	64	48	128	40
None	32	64	48	128	40
Average	32	64	48	128	40

	CaO extracted				
Treatment	Bray	Morgan	Hester I	Hester II	pH
None	560	1120	840	210	6.3
None	560	560	840	420	6.3
Average	560	840	840	315	6.3

	MgO extracted			
Treatment	Bray	Morgan	Hester I	Hester II
None	66	66	50	50
None	33	33	50	50
Average	50	50	50	50

Table 53 - Harvey Darden - Cont'd. - Yield of peanuts in pounds per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments		Yield Lbs./A	NO_3	P_2O_5	K_2O	8/2/41 NO_3	8/2/41 P_2O_5	8/2/41 K_2O
400 lbs.	0-0-12	1820				-	M	L
	0-6-12	2180				-	M	L
	0-12-12	2210				-	M	L
	0-18-12	2060				-	M	L
	0-24-12	2380	No tests made			-	M	L
	Check	1750	in July			-	M	L
	0-12-0	2110				-	M	L
	0-12-6	2220				-	M	L
	0-12-18	2180				-	L	L
	0-12-24	2220				-	L	L

Remarks: - Plants were about 24 inches in diameter at time tissue tests were made.

Table 54 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from two modifications of Purvis' absorption solution containing the equivalent of 400 and 800 pounds per acre of K_2O and 64 and 128 pounds per acre of P_2O_5 in the original solution.

Soil type: - Frederick silt loam
Location: - Max Sterrett
Brownsburg

Crop: - Corn
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted						
	Bray	Thornton	Morgan	Hester I	Hester II	Purvis	
	(contained in original solution:					400	800)
None	160	80	120	90	60	200	600
None	120	80	80	60	60	240	600
Average	140	80	100	75	60	220	600

Treatment	P_2O_5 extracted					
	Morgan	Hester I	Hester II	Thornton	Purvis	
	(contained in original solution:				64	128)
None	8	32	8	8	64	104
None	4	32	16	4	64	112
Average	6	32	12	6	64	108

Treatment	CaO extracted				
	Bray	Morgan	Hester I	Hester II	pH
None	1680	1120	1260	1260	6.7
None	1680	1120	1260	1680	6.7
Average	1680	1120	1260	1470	6.7

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester III
None	66	66	100	100
None	66	66	100	100
Average	66	66	100	100

Table 55 - Max Sterett - Cont'd. - Yield of corn in bushels per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizers treatments		Yield: Bu./A	7/15/41 NO_3	P_2O_5	K_2O	8/19/41 NO_3	P_2O_5	K_2O
300 lbs.	4-0-6	28.1	VH	VH	VH	L	L	L
	4-6-6	27.7	VH	VH	VH	L	M	M
	4-12-6	33.1	VH	M	VH	VL	L	M
	4-18-6	30.7	VH	H	VH	L	L	M
	4-24-6	21.0	VH	M	VH	L	M	L
	Check	18.1	VH	M	VH	M	L	M
	4-12-0	25.0	VH	VH	VH	L	M	M
	4-12-12	27.3	VH	H	VH	M	M	M
	4-12-18	24.9	VH	VH	VH	M	M	M
	4-12-24	28.3	VH	VH	VH	H	M	L

Remarks: - Fertilizer was applied in the row at planting. Yields markedly decreased by severe drought which extended from mid-July to late September.

Plants were beginning to silk and tassel at time of first testing. Second tests were made when plants were in early dough stage.

Table 56 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from two modifications of Purvis' absorption solution containing the equivalent of 400 and 800 pounds per acre of K_2O and 64 and 128 pounds per acre of P_2O_5 in the original solution.

Soil type: - Frederick silt loam
Location: - Boyd Stuart
Brownsburg

Crop: - Corn
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted						
	Bray	Thornton	Morgan	Hester I	Hester II	Purvis	
(contained in original solution:						400	800)
None	280	200	160	120	120	280	680
None	160	80	80	60	60	320	720
Average	220	140	120	90	90	300	700

Treatment	P_2O_5 extracted					
	Morgan	Hester I	Hester II	Thornton	Purvis	
(contained in original solution:					64	128)
None	16	48	8	4	64	124
None	8	80	48	4	64	124
Average	12	64	28	4	64	124

Treatment	CaO extracted				
	Bray	Morgan	Hester I	Hester II	pH
None	1680	2240	2940	2940	7.2
None	1680	3360	2940	2940	7.3
Average	1680	2800	2940	2940	7.25

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester II
None	266	266	250	250
None	199	266	300	300
Average	230	266	275	275

Table 57 - Boyd Stuart - Cont'd. - Yield of corn in bushels per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer	Yield:	7/15/41			8/19/41		
treatments	Bu./A:	NO_3	P_2O_5	K_2O	NO_3	P_2O_5	K_2O
300 lbs. 4-0-6	42.3	VH	VH	VH	L	M	H
4-6-6	49.4	VH	VH	VH	L	H	H
4-12-6	45.7	VH	VH	VH	M	H	H
4-18-6	44.1	VH	VH	VH	L	M	H
4-24-6	48.1	VH	VH	VH	M	M	H
Check	37.7	VH	VH	VH	M	M	M
4-12-0	42.1	VH	VH	VH	H	L	L
4-12-12	36.0	VH	H	VH	M	VL	M
4-12-18	48.9	VH	VH	H	L	L	M
4-12-24	55.0	VH	VH	VH	H	M	M

Remarks: - Fertilizer was applied in the row at planting. Yields were decreased to some extent due to severe drought which extended from mid-July to late September.

Plants were beginning to silk and tassel when first tests were made. They were in early dough stage at time of second testing.

Table 58 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from two modifications of Purvis' absorption solution containing the equivalent of 400 and 800 pounds per acre of K_2O and 64 and 128 pounds per acre of P_2O_5 in the original solution.

Soil type: - Hagerstown stony clay loam
Location: - Billy McCowin
Brownsburg

Crop: - Corn
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted						
	Bray	Thornton	Morgan	Hester I	Hester II	Purvis	
			(contained in original solution:			400	800)
None	280	200	160	120	120	240	560
None	200	160	120	90	90	280	560
Average	240	180	140	105	105	260	560

Treatment	P_2O_5 extracted					
	Morgan	Hester I	Hester II	Thornton	Purvis	
		(contained in original solution:			64	128)
None	0	16	4	4	64	120
None	0	16	4	4	64	120
Average	0	16	4	4	64	120

Treatment	CaO extracted				
	Bray	Morgan	Hester I	Hester II	pH
None	1120	560	840	840	5.8
None	1120	560	840	840	5.8
Average	1120	560	840	840	5.8

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester II
None	133	133	100	100
None	133	133	100	100
Average	133	133	100	100

Table 59 - Billy McCowin - Cont'd. - Yield of corn in bushels per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments		Yield: Bu./A	7/15/41 NO_3	7/15/41 P_2O_5	7/15/41 K_2O	8/19/41 NO_3	8/19/41 P_2O_5	8/19/41 K_2O
300 lbs.	4-0-6	15.9	VH	H	VH	L	M	M
	4-6-6	18.9	VH	VH	VH	L	M	H
	4-12-6	13.1	VH	VH	VH	L	H	H
	4-18-6	19.9	VH	VH	VH	VL	H	H
	4-24-6	21.4	VH	VH	VH	VL	H	M
	Check	12.7	VH	H	VH	VL	H	H
	4-12-0	19.1	VH	H	VH	VL	M	H
	4-12-12	14.7	VH	VH	VH	H	M	H
	4-12-18	17.1	VH	VH	VH	VL	H	VH
	4-12-24	17.0	VH	H	VH	VL	H	H

Remarks: - Fertilizer was applied in the row at planting. Yields were decreased greatly due to extreme drouth extending from mid-July to late September.

Severe magnesium deficiency symptoms appeared in July and continued throughout the season.

First tissue tests were made when corn was beginning to silk and tassel. Second tests were made in the early dough stage.

Table 60 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from two modifications of Purvis' absorption solution containing the equivalent of 400 and 800 pounds per acre of K_2O and 64 and 128 pounds per acre of P_2O_5 in the original solution.

Soil type: - Frederick silt loam
Location: - Fred Talley
Brownsburg

Crop: - Corn
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted: Bray	Thornton	Morgan	Hester I	Hester II	Purvis 400	Purvis 800
			(contained in original solution:			400	800)
None	240	200	240	150	150	200	400
None	280	200	240	150	150	200	400
Average	260	200	240	150	150	200	400

Treatment	P_2O_5 extracted: Morgan	Hester I	Hester II	Thornton	Purvis 64	Purvis 128
		(contained in original solution:			64	128)
None	4	8	4	8	64	126
None	4	4	4	8	64	128
Average	4	6	4	8	64	127

Treatment	CaO extracted: Bray	Morgan	Hester I	Hester II	pH
None	280	280	420	420	5.9
None	280	280	420	420	5.9
Average	280	280	420	420	5.9

Treatment	MgO extracted: Bray	Morgan	Hester I	Hester II
None	66	66	50	50
None	66	66	50	50
Average	66	66	50	50

Table 61 - Fred Talley - Cont'd. - Yield of corn in bushels per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments		Yield: Bu./A	7/15/41 NO_3	7/15/41 P_2O_5	7/15/41 K_2O	8/19/41 NO_3	8/19/41 P_2O_5	8/19/41 K_2O
300 lbs.	4-0-6	28.1	VH	VH	VH	M	M	VH
	4-6-6	29.4	VH	VH	VH	M	M	VH
	4-12-6	29.1	VH	VH	VH	M	M	H
	4-18-6	36.3	VH	VH	VH	H	VH	VH
	4-24-6	38.1	VH	VH	VH	M	L	VH
	Check	30.1	VH	VH	VH	L	L	VH
	4-12-0	26.0	VH	VH	VH	L	L	VH
	4-12-12	34.6	VH	VH	VH	L	H	VH
	4-12-18	29.1	VH	VH	VH	L	H	VH
	4-12-24	31.7	VH	VH	VH	L	H	VH

Remarks: - Fertilizer was applied in the row at planting. Yields were markedly decreased by severe drought which extended from mid-July to late September.

First tissue tests were made when corn was beginning to silk and tassel. Second tests were made during the early dough stage.

Table 62 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by different rapid soil test extracting solutions, and pounds per acre of K_2O and P_2O_5 absorbed by the soil from two modifications of Purvis' absorption solution containing the equivalent of 400 and 800 pounds per acre of K_2O and 64 and 128 pounds per acre of P_2O_5 in the original solution.

Soil type: - Frederick silt loam
Location: - Richard Beard
Brownsburg

Crop: - Corn
Crop year: - 1941

Experiment: - Fertilizer ratios experiment for calibration of rapid soil tests.

Treatment	K_2O extracted						
	Bray	Thornton	Morgan	Hester I	Hester II	Purvis	
(contained in original solution:						400	800)
None	360	240	240	150	120	200	400
None	160	160	160	120	120	200	400
Average	260	200	200	135	120	200	400

Treatment	P_2O_5 extracted					
	Morgan	Hester I	Hester II	Thornton	Purvis	
(contained in original solution:					64	128)
None	8	16	8	16	60	124
None	8	16	8	24	62	124
Average	8	16	8	20	61	124

Treatment	CaO extracted				
	Bray	Morgan	Hester I	Hester II	pH
None	560	560	840	840	6.2
None	560	560	840	840	6.1
Average	560	560	840	840	6.15

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester II
None	133	133	100	150
None	133	133	100	100
Average	133	133	100	125

Table 63 - Richard Beard - Cont'd. - Yield of corn in bushels per acre and plant tissue tests. Average of duplicate treatments and tissue tests.

Fertilizer treatments	Yield Bu./A	7/15/41 NO_3	7/15/41 P_2O_5	7/15/41 K_2O	8/19/41 NO_3	8/19/41 P_2O_5	8/19/41 K_2O
300 lbs. 4-0-6	26.1	VH	M	VH	M	L	H
4-6-6	36.6	VH	VH	VH	M	H	VH
4-12-6	28.6	VH	H	VH	M	M	H
4-18-6	31.4	VH	H	VH	M	M	H
4-24-6	32.6	VH	H	VH	L	M	VH
Check	32.6	VH	H	VH	L	H	VH
4-12-0	25.1	VH	VH	VH	M	M	M
4-12-12	28.0	VH	VH	VH	M	VH	VH
4-12-18	29.1	VH	VH	VH	H	H	H
4-12-24	29.7	VH	VH	VH	VL	H	H

Remarks: - Fertilizer applied in the row at planting. Yields were markedly decreased due to a severe drought which extended from mid-July to late September.

First tissue tests were made when corn began to silk and tassel. Second tests at time it was in early dough stage.

Table 64 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Frederick silt loam
Location: - J. K. Livesay
Staunton

Crop: - Corn
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

Treatment	K_2O extracted: Bray	Thornton	Morgan	Hester I	Hester II
Check	40	40	40	30	30

	P_2O_5 extracted: Morgan	Hester I	Hester II	Thornton
Check	8	16	12	16

	CaO extracted: Bray	Morgan	Hester I	Hester II
Check	1120	1680	840	420

	MgO extracted: Bray	Morgan	Hester I	Hester II
Check	60	60	45	22

Table 65 - Yields of corn in bushels per acre and plant tissue tests.

Fertilizer treatments	Yield: Bu./A	7/19/41			7/26/41		
		NO_3	P_2O_5	K_2O	NO_3	P_2O_5	K20
Check	23.0	M	H	VL	M	M	VL
300 lbs. 0-12-0	29.0	M	M	M	M	M	M
0-12-4	34.2	M	M	VL	H	H	H
4-12-0	32.0	H	H	VL	H	H	VL
4-12-4	40.6	H	L	VL	H	M	VL
4-24-4	45.0	H	VH	VL	H	M	VL
4-12-8	47.2	M	M	H	M	M	H
4-24-8	49.8	H	H	H	H	M	H
0-12-0 + M	40.0	H	M	H	H	H	VL

Corn was about 40 inches high at first testing and just beginning to silk and tassel at time second tests were made.

Table 66 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Hagerstown clay loam
Location: - T. H. Clemmer
Staunton

Crop: - Corn
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

	K_2O extracted				
Treatment	Bray	Thornton	Morgan	Hester I	Hester II
Check	40	40	40	30	30

	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
Check	8.0	12	16.0	16.0

	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	3360	1120	2940	2940

	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	60	180	180	135

Table 67 - Yields of corn in bushels per acre and plant tissue tests.

Fertilizer treatments	Yield: Bu./A	7/9/41 NO_3	7/9/41 P_2O_5	7/9/41 K_2O	7/26/41 NO_3	7/26/41 P_2O_5	7/26/41 K_2O
Check	36.4	H	L	VL	H	H	M
300 lbs. 0-12-0	47.4	H	M	VL	M	H	H
0-12-4	52.0	H	M	M	H	L	H
4-12-0	50.2	H	L	VL	H	H	H
4-12-4	53.6	H	M	H	H	H	H
4-24-4	64.2	H	M	H	H	H	VL
4-12-8	62.8	VH	M	H	H	M	H
4-24-8	67.4	H	VL	H	H	M	H
0-12-0 M	55.2	H	L	M	H	H	H

Corn was about 40 inches high at first testing and just beginning to silk and tassel at time second tests were made.

Table 68 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Holston fine sandy loam
Location: - O. C. Flory
Staunton

Crop: - Corn
Crop year: - 1941

Experiment : - Comparison of fertilizer ratios with manure and phosphate.

Treatment	K_2O extracted: Bray	Thornton	Morgan	Hester I	Hester II
Check	120	40	40	30	30

	P_2O_5 extracted: Morgan	Hester I	Hester II	Thornton
Check	8	16	16	32

	CaO extracted: Bray	Morgan	Hester I	Hester II
Check	1120	1120	2520	2520

	MgO extracted: Bray	Morgan	Hester I	Hester II
Check	60	30	45	22

Table 69 - Yields of corn in bushels per acre and plant tissue tests.

Fertilizer treatments	Yield: Bu./A	7/9/41 NO_3	P_2O_5	K_2O	7/26/41 NO_3	P_2O_5	K_2O
Check	32.8	M	M	M	VL	H	M
300 lbs. 0-12-0	35.0	L	H	H	L	H	VL
0-12-4	44.0	H	H	H	M	M	M
4-12-0	40.2	H	H	H	M	H	VH
4-12-4	49.2	H	VH	VH	VH	VH	H
4-24-4	51.6	M	H	M	M	H	M
4-12-8	54.2	H	VH	VH	L	H	H
4-24-8	58.6	H	H	H	H	H	M
0-12-0 /M	44.6	VH	VH	VH	M	H	H

Corn was about 40 inches high at first testing and just beginning to silk and tassel at time second tests were made.

Table 70 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Jefferson fine sandy loam
Location: - C. E. Ruff
Staunton

Crop: - Corn
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

Treatment	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Check	40	40	40	30	30

	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
Check	8.0	24.0	16.0	16.0

	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	2800	3360	1680	2100

	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	60	60	90	45

Table 71 - Yields of corn in bushels per acre and plant tissue tests.

Fertilizer treatments	Yield: Bu./A	7/9/41 NO_3	7/9/41 P_2O_5	7/9/41 K_2O	7/26/41 NO_3	7/26/41 P_2O_5	7/26/41 K_2O
Check	26.4	H	H	VL	M	M	L
300 lbs. 0-12-0	35.0	H	H	VL	M	H	H
0-12-4	42.0	M	H	VL	H	VL	H
4-12-0	37.4	M	H	L	H	H	H
4-12-4	45.8	H	H	VL	H	H	H
4-24-4	49.6	H	VH	VL	H	H	VH
4-12-8	56.4	H	VH	H	H	H	L
4-24-8	60.1	H	VH	H	H	H	H
0-12-0 AM	42.4	H	VH	H	H	H	H

Corn was about 40 inches high at first testing and just beginning to silk and tassel at time second tests were made.

Table 72 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Elk loam
Location: - M. Zimmerman
Staunton

Crop: - Corn
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

Treatment	K_2O extracted: Bray	Thornton	Morgan	Hester I	Hester II
Check	160	40	40	30	30

	P_2O_5 extracted: Morgan	Hester I	Hester II	Thornton
Check	16	16	32	16

	CaO extracted: Bray	Morgan	Hester I	Hester II
Check	3920	2800	2100	2940

	MgO extracted: Bray	Morgan	Hester I	Hester II
Check	180	180	225	180

Table 73 - Yields of corn in bushels per acre and plant tissue tests.

Fertilizer treatments	Yield: Bu./A	7/8/41 NO_3	7/8/41 P_2O_5	7/8/41 K_2O	7/26/41 NO_3	7/26/41 P_2O_5	7/26/41 K_2O
Check	37.2	M	H	VH	M	H	VH
300 lbs. 0-12-0	48.6	M	H	VH	H	M	H
0-12-4	56.8	H	H	VH	VL	M	M
4-12-0	51.5	H	H	H	H	H	H
4-12-4	60.4	H	M	H	H	H	H
4-24-4	62.6	H	H	H	VH	M	VH
4-12-8	68.2	H	H	VH	VH	M	VH
4-24-8	71.0	M	M	H	VL	H	VH
0-12-0 AM	56.2	M	M	VH	H	H	M

Corn was about 40 inches high at first testing and just beginning to silk and tassel at time second tests were made.

Table 74 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Berks silt loam
Location: - H. L. Myers
Staunton

Crop: - Wheat
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

Treatment	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Check	160	80	160	60	30

	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
Check	8	16	16	8

	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	3360	3920	2100	2940

	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	240	240	225	180

Table 75 - Yields of wheat in bushels per acre

Fertilizer treatments		Yield Bu./A
Check		6.1
300 lbs.	0-12-0	11.4
	0-12-4	15.0
	4-12-0	13.6
	4-12-4	16.0
	4-24-4	18.3
	4-12-8	17.7
	4-24-8	19.4
	0-12-0 AM	15.1

Table 76 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Berks silt loam
Location: - H. L. Myer
Staunton

Crop: - Wheat
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

Treatment	K_2O extracted: Bray	Thornton	Morgan	Hester I	Hester II
Check	230	80	200	270	210

	P_2O_5 extracted: Morgan	Hester I	Hester II	Thornton
Check	3	12	8	8

	CaO extracted: Bray	Morgan	Hester I	Hester II
Check	3920	1680	1680	1680

	MgO extracted: Bray	Morgan	Hester I	Hester II
Check	180	120	135	90

Table 77 - Yields of wheat in bushels per acre

Fertilizer treatments		Yield Bu./A
Check		6.8
300 lbs.	0-12-0	12.0
	0-12-4	15.1
	4-12-0	13.6
	4-12-4	17.2
	4-24-4	20.0
	4-12-3	18.1
	4-24-8	21.4
	0-12-0 /M	16.3

Table 78 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Elk silt loam
Location: - M. Zimmerman
Staunton

Crop: - Wheat
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

Treatment	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Check	240	120	240	270	150

	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
Check	32	32	24	16

	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	1120	3920	1680	1260

	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	480	360	450	225

Table 79 - Yields of wheat in bushels per acre

Fertilizer treatments	Yield Bu./A
Check	8.2
300 lbs. 0-12-0	11.1
0-12-4	12.5
4-12-0	11.7
4-12-4	13.8
4-24-4	16.0
4-12-8	15.0
4-24-8	16.8
0-12-0 /M	14.0

Table 80 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Jefferson fine sandy loam
Location: - C. E. Ruff
Staunton

Crop: - Wheat
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

	K_2O extracted				
Treatment	Bray	Thornton	Morgan	Hester I	Hester II
Check	80	40	160	60	30

	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
Check	16	24	16	32

	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	3360	2800	2940	2940

	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	180	180	180	90

Table 81 - Yields of wheat in bushels per acre.

Fertilizer treatments		Yield Bu./A
Check		6.3
300 lbs.	0-12-0	9.0
	0-12-4	11.4
	4-12-0	9.5
	4-12-4	12.0
	4-24-4	14.4
	4-12-8	13.0
	4-24-8	14.6
	0-12-0 /M	11.4

Table 82 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Hagerstown clay loam
Location: - Tom Clemmer
Staunton

Crop: - Wheat
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

Treatment	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Check	240	80	40	30	30

Treatment	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
Check	16	24	16	8

Treatment	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	2800	3360	2100	2520

Treatment	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	180	180	225	135

Table 83 - Yields of wheat in bushels per acre

Fertilizer treatments	Yield Bu./A
Check	9.0
300 lbs. 0-12-0	15.0
0-12-4	17.0
4-12-0	15.6
4-12-4	18.2
4-24-4	22.4
4-12-8	19.3
4-24-8	22.9
0-12-0 M	17.9

Table 84 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Frederick silt loam
Location: - J. K. Livesay
Staunton

Crop: - Wheat
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

Treatment	K_2O extracted: Bray	Thornton	Morgan	Hester I	Hester II
Check	40	40	40	30	30

	P_2O_5 extracted: Morgan	Hester I	Hester II	Thornton
Check	8	24	16	16

	CaO extracted: Bray	Morgan	Hester I	Hester II
Check	2240	3360	3360	2940

	MgO extracted: Bray	Morgan	Hester I	Hester II
Check	30	30	45	22

Table 85 - Yields of wheat in bushels per acre.

Fertilizer treatments		Yield Bu./A
Check		9.4
300 lbs.	0-12-0	15.0
	0-12-4	17.6
	4-12-0	16.1
	4-12-4	19.4
	4-24-4	23.6
	4-12-8	21.2
	4-24-8	23.8
	0-12-0 /M	17.8

Table 86 - Pounds per acre of K_2O, P_2O_5, CaO and MgO removed by various rapid soil test extracting solutions.

Soil type: - Holston fine sandy loam
Location: - O. C. Flory
Staunton

Crop: - Barley
Crop year: - 1941

Experiment: - Comparison of fertilizer ratios with manure and phosphate.

Treatment	K_2O extracted				
	Bray	Thornton	Morgan	Hester I	Hester II
Check	40	40	40	30	30

	P_2O_5 extracted			
	Morgan	Hester I	Hester II	Thornton
Check	32	32	48	16

	CaO extracted			
	Bray	Morgan	Hester I	Hester II
Check	1680	3920	2520	2520

	MgO extracted			
	Bray	Morgan	Hester I	Hester II
Check	60	120	45	90

Table 87 - Yields of barley in bushels per acre

Fertilizer treatments	Yield Bu./A
Check	15.1
300 lbs. 0-12-0	27.6
0-12-4	38.0
4-12-0	31.4
4-12-4	42.0
4-24-4	45.2
4-12-8	45.2
4-24-8	48.4
0-12-0 /M	39.2

PART III

LABORATORY EVALUATION OF TESTING PROCEDURES, EXTRACTING SOLUTIONS AND ABSORPTION SOLUTIONS

A. CRITIQUE OF TESTING PROCEDURES.

Soil samples were extracted in groups of ten. Duplicate extractions were made on two random samples in each group of ten.

Table 88 shows the plus or minus variation in readings on duplicate extractions for each nutrient with each extractant and absorption solution. Also shown is the effective range of readings possible with each extractant and testing procedure that was used.

As a result of his quantitative studies, Brandt (5) arrived at the following recommendations as to the ranges of values which rapid soil tests should be able to cover for significance in crop response under Virginia conditions:

Readily acid soluble P_2O_5 ----	25-200	pounds	per	acre
Total replaceable K_2O----------	75-400	"	"	"
" " CaO --------	250-3500	"	"	"
" " MgO --------	100-2000	"	"	"

Except in the case of magnesium, the range of reading values permitted by the testing procedures used in this study approximate Brandt's recommendations very closely.

Barber's work (1) showed that none of the three extractants used

Table 88 - Range of soil test values possible with the testing procedures used in this study, and the reading error on duplicate extractions secured with five extracting solutions and one absorption solution.

Extractant	K_2O		P_2O_5		CaO		MgO	
	Range Lbs./A.	Reading Error	Range Lbs./A.	Reading Error	Range Lbs./A.	Reading Error	Range Lbs./A.	Reading Error
Bray	40-400	± 80	-------	-------	140-5600	± 560	30-600	± 66
Thornton	40-400	± 40	3-128	± 16	--------	-----	------	-------
Morgan	40-400	± 80	3-128	± 8	140-5600	±1360	30-600	± 66
Hester I	30-300	± 30	3-128	± 16	105-4200	±1890	23-450	± 50
Hester II	30-300	± 30	3-128	± 16	105-4200	±1890	23-450	± 50
Purvis (Absorption Solution)	40-400	±120	2-64	± 16	--------	----	------	-----

by him (Bray, Morgan, Hester II) gave quantitative displacement of exchangeable magnesium. In practice, the limited range of the magnesium test was still sufficient to cover the concentrations encountered with the extracting solutions used in the present investigation.

Reading errors for K_2O, P_2O_5 and MgO were rarely greater than the difference between two adjacent standards. The series of standards used (p. 29) were graduated in larger increments in the upper range than in the lower and middle ranges. Reading errors were consequently greater at the higher levels of concentration. The differences in reading accuracy shown in Table 88 between extractants were a reflection of their relative extracting powers, particularly with reference to K_2O and P_2O_5 .

For purposes of initial calibration of a rapid soil test, close continuity of values over the reading range is desirable. It is suggested that a colorimeter be used in calibration studies to eliminate errors due to human factors of vision and judgement. Once the calibration has been worked out, a series of permanent color standards would be desirable. Since the experimental work reported here was carried on, satisfactory permanent standards made up in plastic have been developed and are being used in Michigan (36). Such a series of standards should be graduated closely enough to permit roughly quantitative interpretation in terms of rates of fertilization. At the same time the graduations should be sufficiently separate and distinct to permit an operator with average vision to make positive comparisons with test solutions.

The eight to ten graduations employed over the color range for K_2O, P_2O_5 and MgO in the present study were too numerous for positive identification of test solutions with one or the other of two adjacent standards. It is recommended that the number of graduations be reduced to five or six for practical use, once the calibration with crop response has been established for the extracting procedure that is to be used.

No determinations for ammonia were made in connection with the potassium tests. The quantity of formaldehyde used in the testing procedure for K_2O was sufficient to permit accurate determinations for potassium in the presence of 15 ppm of ammonia (9). It is felt that a number of very high readings for potash were higher than they should have been, due to interference from ammonium ion in concentrations greater than 15 ppm. It is felt that the inclusion of formaldehyde is a valuable refinement in the potash testing procedure. It is suggested that some test for ammonia also be employed as a routine procedure in connection with all potash determinations. It is further suggested that correction factors be developed to adjust for ammonia present in concentrations greater than 15 ppm (or concentrations of ammonia greater than that which can be eliminated by the proportion of formaldehyde included in whatever testing procedure is finally adopted.) On extracts which contain excessive concentrations of ammonia, a flame photometer might be used for the potassium determination.

In this connection, it should be said that the addition of 40% formaldehyde results in dilution of the developed test. The proportion that is added must not be so great as to unduly impair the sensitivity of the test. The effect of varying dilutions upon the accuracy of test results should be determined in a laboratory study.

Readings for CaO within the ranges listed in Table 88 were accurately duplicable when standard solutions were used. However, readings on soil extracts were erratic, particularly in the higher range of concentrations. The differences in reading error for calcium (Table 88) are of the same order as the differences in pH of the extractants. Calcium oxalate is soluble below pH 4.0 (2). Both Hester I and Hester II approach this (pH 4.2 and 4.0 respectively). Morgan's solution is pH 4.8. Bray's solution (as used here) is near neutral. Apparently, small changes in pH of the extract resulting from relatively small variations in buffer capacity and base supply in the soils extracted gave rise to rather wide variations in completeness of calcium precipitation with Hester I and II. Similar variations in pH of extract apparently affected completeness of calcium precipitation to a lesser extent with Morgan's and least of all with Bray's. The higher initial pH of these solutions would be expected to raise the pH of the extracts out of the range where slight changes in acidity might markedly influence the completeness of the precipitation.

Variations in solubility of the calcium oxalate as influenced by varying pH also affect the grain size of the flocculate. Small crystals are associated with conditions of very low solubility. Increased solubility brought about by lower pH (or a change in any other factor which promotes increased solubility) results in equilibrium conditions under which small crystals dissolve and large crystals grow (surface effect). Variations in grain size of the suspended precipitate greatly affect light transmission and accuracy of readings.*

On the basis of the concentration of displacing cations, Bray's extractant would be expected to displace more calcium than the others. The fact that average calcium readings were actually lower with Bray's may be partly explained by the fact that, in many instances, its higher pH resulted in precipitates with a particle size which gave erroneously low readings. In some cases, this may have been due to the extremely small grain size of the precipitate under conditions of very low solubility. Frequently, however, a very coarse, coagulated flocculate was formed which gave low readings on soils which showed high values for CaO with the other extractants. In these cases, the low buffer capacity of Bray's solution as used here apparently permitted the pH of the extract to be raised to the iso-electric point of the precipitate by the calcium (and other bases) removed from these soils.

The intermediate pH and the greater buffer capacity in Morgan's Universal extractant tended to correct these errors. Even with Morgan's however, performance was far from satisfactory.

The need for further work in refining the test for CaO is indicated. In the work the following points should be considered:

1. Determine the pH in the developed test solution necessary to assure complete precipitation of calcium oxalate.

2. Determine the most favorable range of pH in the developed

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* Note: The intensity of transmitted light is inversely proportional to the sixth power of the particle radius.

test solution to give precipitates of the most stable particle size for turbidimetric reading.

3. Adopt an extracting solution sufficiently high in buffer capacity to eliminate marked variations in the pH of the extract resulting from the buffering action of the soil. (Soil-to-solution extracting ratios should also be considered in this connection).

4. The pH at which the extracting solution should be buffered will be determined by considerations bearing on the efficiency of calcium removal from the soil. It may or may not fall in the range determined under 2 (above). The basicity of the oxalate reagent will need to be adjusted accordingly. (For purposes of comparison, it is of interest to note that Goss (24) recommends making up sodium oxalate in 2% sodium hydroxide for the calcium test. The ammonium oxalate test solution used in this study contained only 0.15% ammonium hydroxide).

In addition to reading errors arising from variations in the pH of the developed test, it must be said that the reading method used was rather unsatisfactory for calcium. Photelometric reading methods are suggested for future calibration studies.

Because of the difficulties that were encountered in visual identification of calcium standards by different operators, the standards for CaO as described in Table 3, p. 29, are reduced in range and number of graduations from those actually used in the study.

The reading error for K_2O with Purvis' absorption solution was exceptionally high. Also the ratio of reading error to range for P_2O_5 with the Purvis solution was very high. At least a part of this error may, perhaps, be interpreted as resulting from variable absorption of K_2O and P_2O_5 by the soil.

A certain degree of error was introduced in all determinations by the volumetric measurement of the soil sample and the small size of sample used. This would not be important in application after a soil testing procedure had been adequately calibrated. However, for calibration studies, it is recommended that larger samples be extracted, and that samples be weighed rather than measured by volume.

B. RELATIVE EXTRACTING POWER OF EXTRACTING SOLUTIONS

1. Potassium

Extracting for quick tests is in the nature of an equilibrium rather than a continuous leaching. The completeness of potassium removal is dependent upon concentration of the extracting ion, base exchange capacity of the soil and its degree of saturation with other ions, particularly calcium and magnesium (8). Length of extracting period is also a factor (25).

Bray (8) has classified certain of the extractants used for potassium in this study as follows:

Type 1. Practically quantitative displacement of exchangeable potassium with soils up to 30 M. E. base exchange capacity per 100 gms of soil:

Bray's 22% sodium perchlorate

Type 2. Quantitative displacement of exchangeable potassium with soils up to 20 M. E. base exchange capacity:

Thornton's 16% sodium nitrite (adjusted to pH 5.0 with acetic acid)

<u>Type 3.</u> <u>Relative</u> displacement of exchangeable potassium with soils up to 5 M. E. base exchange capacity:

Morgan's 10% sodium acetate plus 3% acetic acid.

<u>Type 4.</u> Extracting solutions so weak that they merely approximate the effect of the soil solution. These are of little value because it has been shown that the potassium in the soil solution has no direct relation to the ability of the soil to keep supplying potassium to a growing crop.

(Probably none of the solutions used in this study would fall in this group).

A two-minute extracting period was employed in this study with Bray's, Thornton's and Morgan's extractants. The twenty-minute extracting period used with Hester I (4% NaAc plus 4% H Ac) and Hester II (2.5% NaAc plus 4% H Ac) would probably place these two extractants in Group 3 with Morgan's solution.

Goss (25) cites data indicating that on Sassafras loam the relative extracting power of three of these extractants was in the order Bray > Morgan > Hester. When the extracting period for Morgan's solution was increased from mere percolation (as described in the original procedure) (39) to fifteen minutes, the amount of potassium displaced was increased into a range somewhat equivalent with Bray's solution.

Barber's comparison of the same three solutions with quantitative data for exchangeable potassium on seventy-five soil samples representing soils from the three soil provinces in Virginia brought out a similar relationship with respect to quantities of K_2O displaced: Quantitative method $>$ Bray $>$ Morgan $>$ Hester (1).

Tables 89, 90 and 91 show the average pounds per acre of K_2O, P_2O_5, CaO and MgO extracted by the different extractants used in this study from soils of the Coastal Plains, Piedmont and Mountain provinces.

The low values for K_2O with Thornton's solution, and the fact that the correlation of the Thornton K_2O tests with previous treatment was low (Tables 4 through 27), indicate that some systematic error in technique was involved. The procedure described by Thornton (48) was modified in this study in four ways. The extracting period was increased from one minute to two minutes. The volume of the developed test was reduced, although the proportion of alcohol to extract remained the same. Neither of these changes could account for reduced readings. The introduction of formaldehyde would have resulted in dilution of the test, which could have reduced density of precipitates. Also, because no pH-meter was readily available, the extracting solution was not always adjusted to pH 5.0 (p. 13). It is doubtful that this would have altered extracting power greatly.

The fact remains that the data for K_2O with Thornton's extracting solution does not appear to be reliable and will be ignored in the remainder of this report.

Table 89 - Average pounds per acre of K_2O, P_2O_5, CaO and MgO extracted by various rapid soil test solutions from soils of the Coastal Plains soil province of Virginia. Each average is based on 74 determinations.

Extractant	Average pounds per acre extracted			
	K_2O	P_2O_5	CaO	MgO
Bray	184	——	1290	90
Thornton	77	68	——	—
Morgan	136	29	1563	102
Hester I	112	31	1002	96
Hester II	103	36	1005	94

Table 90 - Average pounds per acre of K_2O, P_2O_5, CaO and MgO extracted by various rapid soil test solutions from soils of the Piedmont soil province of Virginia. Each average is based on 18 determinations.

Extractant	Average pounds per acre extracted			
	K_2O	P_2O_5	CaO	MgO
Bray	107	----	1836	72
Thornton	40	51	----	--
Morgan	140	25	1991	90
Hester I	63	30	1120	89
Hester II	75	33	1143	81

Table 91 - Average pounds per acre of K_2O, P_2O_5, CaO and MgO extracted by various rapid soil test solutions from soils of the Limestone Valley of Virginia. Each average is based on 154 determinations.

Extractant	Average pounds per acre extracted			
	K_2O	P_2O_5	CaO	MgO
Bray	183	----	1764	164
Thornton	58	14	----	----
Morgan	135	17	2149	206
Hester I	95	12	1454	200
Hester II	95	13	1462	173

The remaining four extractants arrange themselves in the order Bray $>$ Morgan $>$ Hester I = Hester II, with respect to quantities of potassium removed. (The variation from this in the Piedmont data is based on only 18 determinations and is probably not significant).

Barber (1) determined base exchange capacity on a number of soils from the three soil provinces of Virginia. While far from definitive, his data does give some indication of the capacities that may be expected in these three areas:

Coastal Plains: 2.1 to 7.9 M. E. per 100 gms

Piedmont: 2.1 to 6.8 M. E. per 100 gms

Mountain Valleys: 9.9 to 11.0 M. E. per 100 gms

On the basis of Bray's classification of extracting solutions (p. 132), it would appear that the data for Morgan's solution and Hester I and II may be interpreted as giving only a roughly relative measure of exchangeable potassium on Coastal Plains and Piedmont soils. On the soils of the mountain valleys these three solutions probably do not give any indication of the total exchangeable potassium supply.

In addition to the greater base exchange capacity in these heavier soils, the supply of calcium and magnesium varies much more widely. The following approximate formula (8) shows the effect of base exchange capacity and of replaceable calcium and magnesium on the extraction of potassium by extracting solutions whose replacing strength in M. E. is less than the total M. E. of replaceable bases in the soil:

$$\text{M. E. of K in sol'n} = \left(\frac{\text{M.E. repl. K}}{\text{M.E. repl. Ca + M.E. repl. Mg}}\right) \times \left(\frac{\text{M.E. repl. Ca + M.E. repl. Mg}}{\text{M.E. Exch. Cap'y}}\right)^{\frac{1}{2}}$$

Under Illinois conditions Bray (8) has found that the fraction of soil potassium that is significant in crop growth is total exchangeable potassium. A quick soil test must measure this fraction, - quantitatively or relatively, - before adequate correlation of soil tests with crop response to fertilization can be made.

From purely theoretical considerations, therefore, it would appear that Morgan's extracting solution, and Hester I and Hester II would be limited in application, as far as potash is concerned, to soils of the Coastal Plains and the Piedmont. Bray's sodium perchlorate and Thornton's potassium extractant should give significant potassium values in these two provinces as well as in the mountain valleys of western Virginia.

It is possible that Morgan's extracting solution might be adapted to the heavier soils by extending the extracting period. Recovery with Hester I and Hester II would probably not be enhanced by extending the extraction period beyond the twenty minutes now employed.

2. Phosphorus

Phosphorus is found in the soil in numerous forms. Water-soluble forms occur naturally, released by decomposition of plant residues and the action of inorganic and organic acids on less soluble forms of phosphorus in the soil. However, the absolute quantity of water-soluble phosphate in the soil at any given time is small, except in localized soil areas during a rather short period after application of soluble forms in commercial fertilizer. This form is readily available to plants and to extraction with water and quick test extracting solutions.

At soil pH's from 6.5 to 8.0 (excess Ca CO_3 less than 2%), water-soluble phosphorus is rapidly converted to calcium phosphate. This is not water-soluble but it is readily available to plants through the action of carbonic acid from CO_2 released by plant roots and decomposing organic matter. It is also easily soluble in acid extracting solutions (51).

Above pH 8.0 (excess Ca CO_3 greater than 2%) the availability of this calcium phosphate is suppressed to the point where it becomes the least available form of soil phosphorus to most crop plants. This form of phosphorus is soluble in acid extractants (51). Thus, a quick soil test under these conditions may show supplies of P_2O_5 that are greater than would be indicated by actual crop response (43).

Below pH 6.0 phosphorus occurs in the soil as basic iron and aluminum phosphates. Fixation of applied phosphates is most rapid and complete in this range (22). The iron and aluminum phosphates are difficultly available to plants and only slightly soluble in acid extractants. However, supplies of this difficultly soluble form may be sufficiently large in the soil to allow a rate of solution adequate for good crop yields (51). Such supplies have been measured by repeated extractions using systematically increasing ratios of extractant to soil (51), or through use of an alkaline extracting solution (20).

Yet another form of soil phosphorus is found in the pH range from 3.0 to 7.0. This is the phosphorus that is adsorbed on the colloids of the clay fraction. Adsorbed phosphorus is normally the most abundant form between pH 5.0 to 6.0 in all soils except sands and light sandy loams low in clay and humus (44). This form is more or less available to plants through displacement by organic anions released by decomposing organic matter (44). The availability of adsorbed phosphorus to plants is low in soils high in colloidal content. However, its availability, even in such soils, can be greatly increased by increasing the degree of phosphate saturation of the anion exchange complex by large applications of phosphate, or by normal applications continued over a period of years (21, 23).

Adsorbed phosphorus may be released by hydrolysis in alkaline extracting solutions, or by anion displacement in acid extracting solutions (16). However, the extent of recovery in acid solutions is dependent upon the concentration and activity of the displacing anion (10). It is occasionally found that even strong acid (0.7 N H Cl) fails to disclose supplies of adsorbed phosphate capable of supporting maximum crop yields (10).

In many soils, organic forms of phosphorus are present in larger supply than the total of the forms listed thus far (4). There is some evidence to indicate that certain crops under certain soils conditions can utilize organic forms of soil phosphorus directly (4). Normally, however, mineralization of organic phosphorus by bacterial and enzyme action is necessary before this form of phosphorus becomes available to plants. Thus, the inorganic forms listed are most significant to crop response, and are the ones which should be measured by rapid soil tests.

In Table 92 are tabulated the normality of the displacing anions, pH and total titratable acidity of the extractants used for phosphorus in this study. On the basis of pH, these solutions increase in acidity in the following order: Morgan, Hester I, Hester II and Thornton.

Table 92 may now be compared with Tables 89 and 90 (Pp. 135, and 136). It will be seen that, with soils of the Coastal Plains and the Piedmont, these extracting solutions gave average soil test values for P_2O_5 that decreased proportionately and in the same order as their active acidities. The results indicate that acid-soluble forms of phosphorus were the important forms being measured, and that adsorbed phosphorus was a negligible fraction of the phosphorus recovered.

With the Limestone Valley soils in Table 91, however, it will be seen that this relationship is somewhat reversed. Comparing Morgan's solution with Hester I and II, the larger recovery with Morgan's would indicate that adsorbed phosphorus was among the forms present in these soils. Goss (25) reports results that indicate greater displacement of adsorbed phosphorus with Morgan's extractant than with solutions with lower anion concentrations. The fact that Thornton's dilute acid extractant removed quantities of phosphorus equivalent to Hester I and Hester II points to the fact that acid soluble forms were probably still the most abundant fraction of phosphorus recovered from the Limestone Valley soils. The low values for P_2O_5 with all extracting solutions on these heavier soils of the Limestone Valley raises a serious question as to whether significant quantities of adsorbed phosphorus may not have remained untouched by the extractions.

Table 92 - Normality of the displacing anion, pH and total titratable acidity of the extractants used for P_2O_5.

Extractant	Formulation	Normality of displacing anion	pH	Titratable acidity
Thornton's (modified)	.05 N H Cl	.05 N	1.4	.05 N
Morgan	10% Na Ac 3% H Ac	1.25 N	4.8	.51 N
Hester I	4% Na Ac 4% H Ac	.98 N	4.2	.69 N
Hester II	2.5% Na Ac 4% H Ac	.87 N	4.0	.69 N

The lower recovery of P_2O_5 from the soils of the Limestone Valley as compared with the Coastal Plains and the Piedmont derive largely from differences in texture and colloidal content of the soils. Goss (25) has shown that soil pH also influences the quantities of phosphorus recovered by different extracting solutions. On acid soils Morgan's extractant removed more phosphorus in the New Jersey study than the other extractants used, all of which carried a lower concentration of displacing anions.

In Table 93 are tabulated P_2O_5 values for the different extractants for a group of Coastal Plains soils samples arranged in order of soil pH. As a group they disclose only a slight correlation between soil pH and the amount of phosphorus removed by the various extracting solutions.

In Table 94 this same group of soil samples is arranged in pairs by locations whence they were taken. Each sample represents the area covered by one of two replications of treatments at each location. At all but two locations, the two samples varied by a difference of 0.1 to 0.7 of a unit of pH. Considering the variation <u>within</u> pairs of samples, it will be seen that with the more acid extractants (Thornton, Hester I and Hester II) there is a tendency for the sample with the higher pH in each pair to give also the higher test for P_2O_5. The test for phosphorus with Morgan's solution follows soil pH in only two pairs of samples, and then the differences do not exceed the limits of reading error (p. 126).

The higher pH of Morgan's solution makes it less sensitive to acid-soluble forms of phosphorus. Its higher anion concentration makes it more sensitive to adsorbed forms of phosphorus. Over the soil pH range

Table 93 - Pounds per acre of P_2O_5 extracted by different soil testing methods, arranged according to the soil pH, and pounds per acre of P_2O_5 absorbed from a solution supplying P_2O_5 at the rate of 64 pounds per acre. Coastal Plains soils.

Basic data table	Soil type	Soil pH	Thornton	Hester II	Hester I	Morgan	Purvis Absorption
32	Lenoir f.s.l.	6.4	64	16	3	16	62
44	Norfolk f.s.l.	6.4	16	32	32	24	8
32	Lenoir f.s.l.	6.3	64	16	3	16	62
52	Norfolk s.l.	6.3	128	48	64	32	40
52	Norfolk s.l.	6.3	128	48	64	32	40
38	Norfolk s.l.	6.2	112	24	16	16	48
30	Norfolk f.s.l.	6.0	80	24	32	16	60
30	Norfolk f.s.l.	6.0	48	16	16	24	60
34	Onslow v.f.s.l.	6.0	64	32	3	8	62
36	Norfolk f.s.l.	6.0	128	48	32	16	48
40	Norfolk f.s.l.	6.0	8	16	16	8	40
50	Norfolk f.s.l.	6.0	128	64	64	32	32
38	Norfolk s.l.	5.9	80	16	16	16	60
40	Norfolk f.s.l.	5.9	8	16	8	8	40
48	Norfolk s.l.	5.9	16	16	16	8	32
34	Onslow v.f.s.l.	5.8	64	32	3	8	60
36	Norfolk f.s.l.	5.8	96	48	16	16	48
42	Norfolk f.s.l.	5.8	96	24	16	24	56
44	Norfolk f.s.l.	5.8	8	16	16	16	16
50	Norfolk f.s.l.	5.8	128	48	64	32	32
42	Norfolk f.s.l.	5.7	48	8	8	16	60
28	Onslow f.s.l.	5.6	48	16	8	16	48
46	Onslow f.s.l.	5.5	24	8	16	16	60
28	Onslow f.s.l.	5.4	32	32	8	24	48
46	Onslow f.s.l.	5.3	24	8	16	16	60
48	Norfolk f.s.	5.2	8	16	8	8	40
	Average P_2O_5 values		63	26	22	18	47

Table 94 - Soil pH, and pounds per acre of P_2O_5 extracted by different rapid soil testing methods, arranged according to location, and pounds per acre of P_2O_5 absorbed from a solution supplying P_2O_5 at the rate of 64 pounds per acre. Coastal Plains soils.

Location (basic data table)	Soil type	Soil pH	Thornton	Hester II	Hester I	Morgan	Purvis Absorption
28-29	Onslow f.s.l.	5.6	*48	16	8	16	48
	" "	5.4	32	32	8	24	48
30-31	Norfolk f.s.l.	6.0	80	24	32	16	60
	" "	6.0	48	16	16	24	60
32-33	Lenoir f.s.l.	6.4	64	16	3	16	62
	" "	6.3	64	16	3	16	62
34-35	Onslow v.f.s.l.	5.8	64	32	3	8	60
	" "	6.0	64	32	3	8	62
36-37	Norfolk f.s.l.	5.8	96	48	16	16	48
	" "	6.0	*128	48	*32	16	48
38-39	Norfolk s.l.	6.2	*112	*24	16	16	48
	" "	5.9	80	16	16	16	60
40-41	Norfolk f.s.l.	6.0	8	16	*16	8	40
	" "	5.9	8	16	8	8	40
42-43	Norfolk f.s.l.	5.8	*96	*24	*16	*24	56
	" "	5.7	48	8	8	16	60
44-45	Norfolk f.s.l.	5.8	8	16	16	16	16
	" "	6.4	*16	*32	*32	*24	8
46-47	Onslow f.s.l.	5.3	24	8	16	16	60
	" "	5.5	24	8	16	16	60
48-49	Norfolk f.s.	5.2	8	16	8	8	40
	" "	5.9	*16	16	*16	8	32
50-51	Norfolk f.s.l.	6.0	128	*64	64	32	32
	" "	5.8	128	48	64	32	32
52-53	Norfolk s.l.	6.3	128	48	64	32	40
	" "	6.3	128	48	64	32	40
Average P_2O_5 values			63	26	22	18	47

* Soil sample pairs within which the sample with the higher test for P_2O_5 is also the sample with the higher pH.

Table 95 - Soil pH, and pounds per acre of P_2O_5 extracted by different rapid soil testing methods, and pounds per acre of P_2O_5 absorbed from two solutions supplying P_2O_5 at rates of 64 and 128 pounds per acre. Limestone Valley soils.

Basic data table	Soil type	Soil pH Value	Morgan	Thorn-ton	Hester I	Hester II	Purvis Absorption 64#	Purvis Absorption 128#
54-55	Frederick s.l.	6.7	8	8	32	8	64	104
	" "	6.7	4	4	32	16	64	112
56-57	Frederick s.l.	7.2	16	4	48	8	64	124
	" "	7.3	8	4	80	48	64	124
58-59	Hagerstown st. c.l.	5.8	0	4	16	4	64	120
	" "	5.8	0	4	16	4	64	120
60-61	Frederick s.l.	5.9	4	8	8	4	64	128
	" "	5.9	4	8	4	4	64	128
62-63	Frederick s.l.	6.2	8	16	16	8	60	124
	" "	6.1	8	24	16	8	62	124
12	Dunmore s.l.,limed	7.6	0	3	3	0		
	" " "	7.7	0	0	3	3		
	" " "	7.4	3	3	3	3		
	" " "	7.5	0	3	0	3		
	" " "	7.4	3	3	3	0		
	" unlimed	6.1	0	0	3	0		
	" "	6.1	3	0	0	0		
	" "	5.9	0	3	3	3		
	" "	6.0	3	3	0	0		
	" "	6.4	0	3	3	3		
14	Dunmore s.l.,limed	7.0	3	32	3	8		
	" " "	6.9	8	32	8	3		
	" " "	6.9	8	80	8	8		
	" " "	7.0	16	8	3	3		
	" " "	6.8	3	3	3	8		
	" " "	6.8	8	16	8	8		
	" unlimed	5.9	8	8	8	8		
	" "	6.1	8	16	8	3		
	" "	6.1	3	3	8	3		
	" "	6.0	3	16	8	3		
	" "	6.0	3	16	3	8		
	" "	6.2	16	8	3	3		

Table 95 - (continued)

Basic data table	Soil type	Soil pH Value	Morgan	Thornton	Hester I	Hester II	Purvis Absorption 64#	Purvis Absorption 128#
15	Dunmore s.l., limed	7.0	3	3	0	3		
	" " "	6.9	3	8	3	8		
	" " "	6.8	8	8	8	3		
	" " "	6.9	3	3	3	3		
	" " "	7.0	8	3	3	8		
	" " "	6.9	3	3	0	3		
	" unlimed	5.8	16	8	0	0		
	" "	6.1	3	0	3	3		
	" "	5.8	16	0	8	3		
	" "	5.7	8	8	3	0		
	" "	5.9	8	3	0	0		
	" "	6.0	8	0	3	3		

covered by these samples, reversion of phosphate by adsorption tends to decrease with pH, while reversion in an acid-soluble form tends to increase with pH (44). Fluctuations in these two forms resulting from soil pH would tend to be blanketed out in tests for P_2O_5 with Morgan's solution. This same tendency would hold for Hester I and II, but to a lesser degree because of their greater acidity and lower anion concentration. The data tends to bear this out. Thus the inter-relationship between anion concentration and active acidity of extracting solutions, and the pH of the soils being tested, can be demonstrated to a limited extent by the data, - when comparisons are limited to samples from the same field.

The differences between locations on similar soils types were much greater than the differences due to soil pH. This would indicate that the quantities of phosphate removed by any of the extractants tested was influenced more by the fertilization and cropping history of a given field than by the soil pH. Information as to previous crops and treatments is not available for the data cited. The data does indicate the importance of such information in the interpretation of soil tests for phosphorus.

The differential behavior of these four extracting solutions with respect to adsorbed and acid-soluble forms of phosphorus suggests a further limitation in their applicability. This limitation is the fact that none of them distinguish between adsorbed and acid-soluble P_2O_5.

Soil pH and pounds per acre of P_2O_5 extracted by the different extracting solutions are tabulated in Table 95 for two groups of Mountain soils. The data for the first group (Basic data tables 54 through 63) reveals a general correlation between soil pH and P_2O_5 for all solutions. The correlation is much more definite with Hester I than with the other extractants. This sort of behavior on heavy soils might be explained if acid-soluble P_2O_5 were the most important form being measured. Burd and Murphy (16) have stated that incomplete measurement of P_2O_5 dissolved in unbuffered acid solutions may result from secondary reactions, including re-precipitation by the calcium also extracted, and adsorption by the unsaturated anion exchange. The use of buffered acids suppresses these secondary reactions to a certain extent by resisting changes in H^+ ion concentration by equilibrium reactions between the soil constituents and the extracting medium.

In interpreting the data for the first group of soils in Table 95, the lower recovery for Thornton and Hester II on the more alkaline soils (as compared with Hester I) might be explained on the basis of inadequate buffering which resulted in disappearance of dissolved P_2O_5 by re-precipitation (as calcium phosphate) and adsorption by the anion exchange complexes of the soil. Excessive buffering at too high a pH in Morgan's solution may have operated against its dissolving as much acid-soluble P_2O_5 initially as Hester I.

The second group of samples in Table 95 are all from one field. They represent similar series of treatments on corn, wheat and clover. Few of the differences in soil test value between plots are greater than would be expected from errors in reading. Except for three questionable values for Thornton's solution, none of the differences between plots would probably be significant in crop response. Annual applications of P_2O_5 have exceeded, by approximately twice, the amounts calculated as having been removed in the crop yields taken from these plots. For this reason, some accumulation would have been expected.

Dunmore silt loam is known to fix phosphate rapidly. From its high colloidal content, it would be expected that this fixation would be largely in an adsorbed form, particularly in the pH range from 4.5 to 6.5 (44). Considering the higher level of pH and the higher calcium tests on the limed plots, however, it would be expected that some fixation as acid soluble calcium phosphate would have occurred on them. The overall uniformity of the tests with these acid extracting solutions on limed and unlimed plots alike does not conform with this latter view.

The high level of phosphate absorption from Purvis' absorption solution by the first 10 samples in Table 95 is an indication of the high reversion capacity of the Limestone Valley soils, generally. The low P_2O_5 values for Dunmore silt loam with all four extracting solutions makes it appear very unlikely that any of them are capable of displacing more than a negligible fraction of adsorbed phosphorus from these heavy soils.

In Table 95 are tabulated data on two groups of samples representing Limestone Valley soils in which fixation of phosphorus by adsorption would be expected to predominate. In the one group significantly increasing supplies of acid soluble phosphorus appear to be associated with increasing pH and calcium supply. In the other, adsorption by the anion complex is apparently so rapid that no accumulation in acid soluble form has taken place at the present levels of phosphate fertility in the soil.

As soil pH approaches 8.0 and as excess $CaCO_3$ exceeds 2%, phosphate availability decreases (51). The question arises, at what level do the increasing phosphate test values when associated with increasing pH cease to be significant in crop response?

The acetate ion replaces adsorbed phosphorus weakly, as compared with the hydroxyl and fluoride ions, for example (20, 10). The data suggests that accumulations of adsorbed phosphorus may have taken place which are not revealed by any of the extracting solutions which were used. Do accumulations of adsorbed phosphorus need to be large enough to register in soil tests with these extractants before they are significant in crop response? Calibration with crop response is impossible if significant levels fall below a negative test.

In summarizing, it may be said that anion concentration and anion activity of acid extracting solutions determine their extracting power for adsorbed P_2O_5. The active acidity (pH) largely determines their extracting power for acid-soluble P_2O_5, although a certain degree of buffering is essential to eliminate interference from calcium and reduce adsorption by the unsaturated anion exchange of the heavier soils.

The four solutions that were studied vary widely in all three properties. Morgan's extractant carries the greatest concentration of displacing anion. There was some evidence to indicate that somewhat more adsorbed phosphorus was removed by Morgan's solution than by the others. However, the displacing anion (acetate) in Morgan's, Hester I and Hester II extractants is a rather inactive one and weak in displacing power. The data indicates that none of them displaced more than negligible quantities of adsorbed P_2O_5, particularly on the heavy soils of the Limestone Valley.

The activity of the displacing anion (Cl^-) in Thornton's phosphorus extractant is high, but its concentration (in the modification that was used) is so low (.05N) that this solution was very ineffective in releasing adsorbed phosphate.

The relative extracting power for soil phosphorus of these four solutions was in the order of their active acidities when applied to the soils of the Piedmont and Coastal Plains. On some of the heavier Limestone Valley soils, particularly above pH 7.0, recovery of phosphate was markedly affected by the extent of buffering in the extractant. However, the effectiveness of the buffering was apparently a function of genetic and cultural soil factors, rather than any consistent relationship based on soil pH or the extent of buffering in the extractant.

No relationship was observed to exist between extracting power and total titratable acidity of the extracting solution.

The data tends to support the assumption that, on the heavier soils of western Virginia, a very considerable fixation of P_2O_5 in adsorbed form does occur. The significance of accumulations of adsorbed phosphorus to crop response on these soils will need to be investigated before final calibration of rapid soil tests for P_2O_5 can be made.

Before such investigations can be carried on, extracting solutions will need to be found which are capable of displacing adsorbed phosphorus and distinguishing it from acid-soluble forms. Bray (10) has suggested the fluoride ion for this purpose. During the calibration studies it may be necessary to use a different extractant for each of these two important forms of soil phosphorus.

3. Calcium

In Table 96 are tabulated the normalities of the displacing cations, separately and in total, and the pH of the extractants used for potassium, calcium and magnesium in this study. Reference is now made to Tables 89, 90 and 91 in which are listed average values for the various nutrients extracted by each extracting solution from soils of the three soil provinces.

For purposes of comparison, it is pointed out that the average recovery of potassium with these four extractants varies closely with cation concentration. The proportionate relationship is much closer to the variation in total cation concentration than to the variation in concentration of either the sodium or the hydrogen ion. Thus, with potassium, at least, it would appear that both cations are active in the extraction, and their combined concentrations determine the quantitativeness of the displacement. (The discrepancy in the case of Bray's extractant on the Piedmont soils is probably not significant, inasmuch as only 18 determinations are involved in each average.)

Roughly the same relationship holds true for calcium with Morgan's solution and Hester I and II. With Bray's extractant, however, some factor other than cation concentration enters into the picture to

Table 96 - Normality of displacing cations and pH of extractants used for K_2O, CaO and MgO.

Extractant	Formulation	Normality of Na^+	Normality of H^+	Total Cation Normality	pH
Bray*	22% Na ClO_4 0.07% H ClO_4	1.803	0.007	1.81	slightly acid
Morgan	10% Na Ac 3% H Ac	0.735	0.514	1.25	4.8
Hester I	4% Na Ac 4% H Ac	0.294	0.686	0.98	4.2
Hester II	2.5% Na Ac 4% H Ac	0.184	0.686	0.87	4.0

*Note: The formulation used for Bray's extractant does not conform either to his neutral 22% Na ClO_4 or his acid (pH 4.8) 22% Na ClO_4 plus 0.7% H ClO_4. Its exact pH is not known.

reverse the expected behavior. The average test values for calcium are less with Bray's solution than with Morgan's, although still higher than with Hester I and II.

The reading error due to coarse flocculates resulting from the relatively high pH and the low buffer capacity of the formulation in which Bray's solution was used in this study has already been described (p. 130). This probably accounts for some of the apparently reduced extracting power for calcium of Bray's solution as compared with Morgan's.

However, at least two other factors should be considered:

1. Lower initial solubility of calcium at the higher pH of Bray's modified formulation.

2. Secondary reactions involving base exchange, and phosphorus and other anions, which result in disappearance of calcium from solution. These would be particularly important with soils high in free carbonates which would markedly raise the pH of the extract.

On a limited number of samples, Barber (1) found the relative extracting powers of the three extractants used by him for calcium to be in the order: Hester II > Morgan's > Bray's perchlorate (same formulation as used in the present study). None of them approached complete displacement of total replaceable calcium as determined by quantitative methods.

Bray(9) claims that the acid perchlorate (22% Na ClO_4 plus 0.7% H ClO_4) will extract all of the replaceable calcium under Illinois conditions. It is doubtful that it would give quantitative displacement from high-lime soils in Virginia. However, from the data cited here it may be inferred that an increase in the acid-buffering of the near neutral perchlorate would have increased its extracting power and the accuracy of readings for CaO.

In Tables 97 and 98 are tabulated pounds per acre of CaO extracted by the different extractants from a number of Coastal Plains and Limestone Valley soils for which pH was also known.

On the Coastal Plains soils in Table 97, only a roughly general relationship exists between pH and CaO values for Morgan's solution. The relationship is, however, more definite with this extractant than with the others. The intermediate pH of Morgan's solution and its relatively high buffer capacity may be credited with making this extractant more sensitive to variations in the level of soil calcium, on these soils and with the testing procedures that were used, than the other solutions tested. The uniformly low readings with Bray's over the pH range covered by these samples may be ascribed to:

1. The low solubility of soil calcium at the high pH of this extractant.

2. The low base exchange capacity of these Coastal Plains soils, which would limit the extent to which base exchange reactions could bring calcium into solution.

The recovery of calcium on these Coastal Plains soils was probably too low for the reading error due to coarse flocculates to have been a significant factor in the low readings with Bray's solution.

The higher base exchange capacity of the Limestone Valley soils, Table 98, provided greater opportunity for base exchange reactions to

Table 97 - Pounds per acre of CaO and MgO extracted by different soil testing methods from soils of the Coastal Plain, arranged according to the soil pH.

Soil type	Soil pH	CaO				MgO			
		Bray	Morgan	Hester I	Hester II	Bray	Morgan	Hester I	Hester II
Lenoir f.s.l.	6.4	280	1120	840	420	133	133	150	150
Norfolk f.s.l.	6.4	280	1120	1260	1260	133	133	100	150
Lenoir f.s.l.	6.3	280	1120	1260	420	133	199	150	150
Norfolk s.l.	6.3	560	1120	840	210	66	66	50	50
Norfolk s.l.	6.3	560	560	840	420	33	33	50	50
Norfolk s.l.	6.2	560	560	420	420	10	10	25	8
Norfolk f.s.l.	6.0	280	560	210	210	10	10	8	8
Norfolk f.s.l.	6.0	280	560	210	210	10	10	8	8
Onslow v.f.s.l.	6.0	560	560	420	420	66	66	50	50
Norfolk f.s.l.	6.0	280	280	210	420	33	33	50	50
Norfolk f.s.l.	6.0	280	1120	1260	1260	66	66	50	50
Norfolk f.s.l.	6.0	560	280	420	420	33	33	50	50
Norfolk s.l.	5.9	560	560	420	420	10	33	25	8
Norfolk f.s.l.	5.9	280	560	840	840	66	33	50	50
Norfolk f.s.	5.9	280	560	840	840	66	33	50	100
Onslow v.f.s.l.	5.8	560	560	420	420	66	66	50	50
Norfolk f.s.l.	5.8	280	280	210	420	33	33	50	50
Norfolk f.s.l.	5.8	560	560	420	420	66	66	50	50
Norfolk f.s.l.	5.8	280	560	840	840	66	66	100	150
Norfolk f.s.l.	5.8	280	280	210	420	66	33	25	50
Norfolk f.s.l.	5.7	280	280	420	420	33	33	25	50
Onslow f.s.l.	5.6	140	280	210	210	10	10	25	25
Onslow f.s.l.	5.5	280	280	420	210	33	10	8	25
Onslow f.s.l.	5.4	280	280	210	210	10	10	8	25
Onslow f.s.l.	5.3	280	280	420	420	33	33	25	25
Norfolk f.s.	5.2	140	560	420	840	66	33	50	100
Average values		355	571	557	501	52	49	49	59

Table 98 - Pounds per acre of CaO and MgO extracted by different rapid soil testing methods from soils of the Limestone Valley, arranged according to soil pH.

Soil type	Soil pH	CaO				MgO			
		Bray	Morgan	Hester I	Hester II	Bray	Morgan	Hester I	Hester II
Frederick s.l.	7.2	1680	2240	2940	2940	266	266	250	250
" "	7.3	1680	3360	2940	2940	199	266	300	300
" "	6.7	1680	1120	1260	1260	66	66	100	100
" "	6.7	1680	1120	1260	1680	66	66	100	100
" "	6.2	560	560	840	840	133	133	100	150
" "	6.1	560	560	840	840	133	133	100	100
" "	5.9	280	280	420	420	66	66	50	50
" "	5.9	280	280	420	420	66	66	50	50
Hagerstown st. c.l.	5.8	1120	560	840	840	133	133	100	100
" " "	5.8	1120	560	840	840	133	133	100	100
Average values		1064	1064	1260	1302	126	139	125	130

bring calcium into solution. As a result, greater variations in reading values for CaO were obtained with Bray's solution than was the case on the Coastal Plains soils.

On the limited group of Frederick silt loam samples, all four extractants gave test results for CaO that correlate fairly well with pH. The higher values with all extractants for the two Hagerstown stony clay loam samples than for the Frederick samples of equivalent pH is what would be expected, considering the higher base exchange capacity of the clay. Exchange reactions, rather than solution reactions would be more important on the clay at this pH. It is interesting to note the greater recovery of CaO with Bray's solution in this situation. This behavior is in contrast to the lower recovery with Bray's (compared with the other extractants) on the two slightly alkaline Frederick silt loam samples, in which case solubility would logically be a dominant factor.

The data in Tables 97 and 98 are far from conclusive as proof of the relationships discussed. They are cited to illustrate certain factors that the author feels were involved in the relative performances of these extracting solutions. They are offered as leads for further work directed towards development of a suitable extractant for calcium.*

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* Note: The data tabulated in Tables 97 and 98 were the author's own laboratory determinations. Other determinations on samples of known pH were made by high school help. The extremely erratic nature of this additional data made it of doubtful significance for this comparison.

In further work with the calcium test, it is suggested that particular attention be given to standardizing the pH of the precipitating medium, - which is the developed test solution. The buffer capacity of the extracting solution and the basicity of the oxalate reagent are the two controllable factors determining this. The buffer capacity of the extractant sblected should be sufficient to overcome the alkalizing effect of Virginia soils high in base exchange capacity, base saturation and free carbonates. The pH selected for standardizing upon in the precipitating medium (developed test solution) should be such as to assure complete precipitation of calcium and yet fall within a range over which particle size of the flocculate is relatively stable. This pH range would need to be determined empirically.

Further considerations in selecting an extracting solution should be an adequate concentration of displacing cations to assure quantitative removal of calcium, together with sufficiently low pH and sufficient buffer capacity to inhibit secondary reactions which remove calcium directly from the extract, particularly with high-lime soils.

None of the extractants studied appear to meet all of these qualifications. Sodium perchlorate (22%) would seem from theoretical considerations, to be the most promising. It will need to be buffered more highly with acid than in the modification that was used. Goss (25) reports removal of much larger quantities of calcium with the acid sodium perchlorate described by Bray (9) than with other extractants, including Morgan's and Hester's original extractant. Certainly, the acid sodium perchlorate solution (22% $NaClO_4$ plus 0.7% $HClO_4$) should be tried. The possibilities of even greater acid buffering should be investigated on soils high in base exchange capacity, base saturation and free carbonates.

4. Magnesium

In Tables 89, 90 and 91, it will be seen that Morgan and Hester I extracted closely equivalent quantities of MgO at all locations. This is in contrast to their performance with CaO, where Morgan's solution extracted consistently greater amounts of CaO than did Hester I.

The lower values for MgO with both Bray's and Hester II, as compared with Morgan and Hester I, particularly on the heavier Limestone Valley soils (Table 91), do parallel the performance of these two extractants with CaO. The lower values for Hester II can be explained on the basis of the lower concentrations of displacing cations (Table 96), as in the case of calcium. The closely equal values for Morgan's and Hester I perhaps resulted from the fact that much smaller amounts of MgO than of CaO were present in the soil, so that differences in displacing power of these two extractants were proportionately too small to show up.

The fact that readings for MgO with Bray's extractant were consistently lower than for the others does not involve a reading error as in the case of calcium. Reading errors for magnesium (Table 88, p. 126) were the same for all extractants, - allowing for the difference in conversion factors made necessary by the differences in soil-to-solution extracting ratios (Table 1, p. 16). As was the case with calcium, lower initial solubility of magnesium, and secondary reactions which remove magnesium from solution at the higher pH's involved in extractions with Bray's solution, must again be taken into account.

The data in Table 97, (p. 158) shows a general correlation between soil pH and magnesium test values for all extractants. The pH range covered is short, so the differences are not large. The correlation between pH and magnesium values is less consistent in Table 98, but the differences in values between soils from different locations is greater. Due to the greater base exchange capacities in these heavier soils, greater variations in magnesium supply would be expected. At the same time, correlation with pH would be expected to be more variable for magnesium than for calcium, because of the greater quantities of calcium originally present in most soils and the generally larger proportion of calcium in liming materials.

With moderate attention to technique, the testing procedure described herein, for magnesium (p. 25) would appear to be highly satisfactory for all the extractants that were used.

The considerations to be kept in mind in selecting an extracting solution for magnesium are much the same as for calcium. The extracting solution should carry a sufficient concentration of displacing cations to assure relatively quantitative removal of replaceable magnesium. At the same time, it should have a sufficiently low pH and sufficient buffer capacity to prevent removal directly out of the extract by secondary reactions, particularly with soils high in base content.

Bray's 22% $NaClO_4$ very probably has an adequate concentration of displacing cations, but seems to be inadequately buffered. The extent to which this shortcoming can be corrected by increasing the acid buffering may be limited by the fact that certain soil organic compounds which interfere with color development may be brought into solution thereby. Goss (25) has reported this difficulty with the acid extractant described by Bray (9). No such problem was encountered with the extractants studied here. The range over which such interference might be expected should be determined by further laboratory studies.

Morgan's extractant and Hester I remove equally large quantities of MgO. Thus, the requirements for relative measurement of MgO would seem to be less exacting than for CaO. For this reason, the primary consideration should be to find an extractant capable of giving relatively quantitative displacement of replaceable calcium. This same extractant would very probably give satisfactory results with magnesium, as well as potassium.

C. ABSORPTION SOLUTIONS

It is well known that the availability of soil phosphorus as well as the efficiency of applied phosphate, vary directly with the degree to which the reversion capacity of the soil has been satisfied, either by phosphorus released from native sources within the soil or by residual accumulations from previous fertilization (10, 21, 23).

Numerous studies have been made of phosphate fixation in soils (20). The procedures used for measuring reversion capacity usually involve saturation from a solution containing excess phosphorus, followed by extraction with various extractants (16, 20).

Similarly, the availability of soil potassium and, indirectly, the efficiency of fertilizer potassium depend upon the degree of saturation or un-saturation of the base exchange complex with respect to potassium (52).

The absorption solutions used in this study were designed to measure the soil requirement for both phosphorus and potassium by the disappearance of these two nutrients from a solution of known original concentration after exposure to a known quantity of soil (41). In theory, it was postulated that crop requirements might be correlated more accurately with the soil requirements for these nutrients in an available form than with soil supplies of diverse and unknown availability as measured by extracting procedures.

In Table 99 are listed soil pH, and pounds per acre and percentage absorption of P_2O_5 and K_2O from a solution supplying 64 pounds and 400 pounds per acre, respectively, of these two nutrients for a group of Coastal Plains soils.

In the case of P_2O_5, a wide range of absorption values was obtained from this solution. There is no general correlation with soil pH, although quite consistently the higher absorption value in each pair of samples from a single location occurs on the sample with the lower pH. It is of interest to note the high percentage absorption on the Onslow and Lenoir samples. This would be expected when the normally higher organic matter content of these soils is considered (23).

It will be noted that the range of absorption values for K_2O is not great, and that there is no consistent correlation with pH.

In Table 100 are listed similar data for a group of Limestone Valley soils. Absorption of P_2O_5 was practically complete for all of these soils from the solution supplying 64 pounds per acre of the nutrient. For this reason the concentration was doubled. Some variations in P_2O_5 absorption developed with the stronger solution. However, percentage absorption was still high, so it would appear that an even higher concentration of P_2O_5 might have been used on these heavy soils.

The second solution was also doubled in K_2O concentration. The increase in pounds per acre of potassium absorbed from the stronger solution is exactly what would be expected of an equilibrium reaction of this sort. However, the greatly increased absorption by the four high-pH samples is contrary to what would be expected of a Donnan equilibrium following the Hofmeister series of bases and their degree of dissociation in the atmosphere of the colloidal micelle (37). The 50% ethyl alcohol in which these two solutions were made up apparently dehydrated the K^+ ion. As a result, it acted more nearly like the H^+ ion in displacing calcium and magnesium from the base exchange. It was thus absorbed most strongly by the soils with the greatest degree of saturation with these heavier bases.

The ethyl alcohol was added to the absorption solutions used in this study to assure clear filtrates for the potassium test. Obviously, this practice introduced an unjustifiable error in the amount of K_2O actually taken up by the soil, - particularly with soils containing

Table 99 - Soil pH, pounds per acre and percentage absorption of P_2O_5 and K_2O by a group of Coastal Plains soils from a solution supplying P_2O_5 at the rate of 64 pounds per acre and K_2O at the rate of 400 pounds per acre.

Location (Basic data tables)	Soil type	Soil pH	Removal from Purvis' Absorption solution P_2O_5 (64 #/A.) lbs.	%	K_2O (400 #/A.) lbs.	%
28-29	Onslow f.s.l.	5.6	48	75	200	50
	" "	5.4	48	75	200	50
30-31	Norfolk f.s.l.	6.0	60	94	120	30
	" "	6.0	60	94	120	30
32-33	Lenoir f.s.l.	6.4	62	97	200	50
	" "	6.3	62	97	200	50
34-35	Onslow v.f.s.l.	5.8	60	94	160	40
	" "	6.0	62	97	200	50
36-37	Norfolk f.s.l.	5.8	48	75	120	30
	" "	6.0	48	75	120	30
38-39	Norfolk s.l.	6.2	48	75	160	40
	" "	5.9	60	94	160	40
40-41	Norfolk f.s.l.	6.0	40	63	120	30
	" "	5.9	40	63	80	20
42-43	Norfolk f.s.l.	5.8	56	88	120	30
	" "	5.7	60	94	160	40
44-45	Norfolk f.s.l.	5.8	16	25	160	40
	" "	6.4	8	13	120	30
46-47	Onslow f.s.l.	5.3	60	94	160	40
	" "	5.5	60	94	120	30
48-49	Norfolk f.s.	5.2	40	63	120	30
	" "	5.9	32	50	120	30
50-51	Norfolk f.s.l.	6.0	32	50	160	40
	" "	5.8	32	50	120	30
52-53	Norfolk s.l.	6.3	40	63	160	40
	" "	6.3	40	63	160	40

Table 100 - Soil pH, pounds per acre and percentage absorption of P_2O_5 and K_2O by a group of Limestone Valley soils from absorption solutions supplying P_2O_5 at rates of 64 and 128 pounds per acre and K_2O at rates of 400 and 800 pounds per acre.

Location (Basic data tables)	Soil type	Soil pH	Removal from Purvis' Absorption solution							
			P_2O_5				K_2O			
			64#		128#		400#		800#	
			lbs.	%	lbs.	%	lbs.	%	lbs.	%
56-57	Frederick s.l.	7.2	64	100	124	97	280	70	680	85
		7.3	64	100	124	97	320	80	720	90
54-55	Frederick s.l.	6.7	64	100	104	81	200	50	600	75
		6.7	64	100	112	88	240	60	600	75
62-63	Frederick s.l.	6.2	60	94	124	97	200	50	400	50
		6.1	62	97	124	97	200	50	400	50
60-61	Frederick s.l.	5.9	64	100	126	98	200	50	400	50
		5.9	64	100	128	100	200	50	400	50
58-59	Hagerstown st.c.l.	5.8	64	100	120	94	240	60	560	70
		5.8	64	100	120	94	280	70	560	70

large amounts of exchangeable calcium and/or magnesium.

Another fundamental error arises from the fact that a large proportion of the potassium in the absorption solution was supplied as K_2HPO_4. The strong absorption of the phosphate ion would promote greater than normal absorption of potassium as the associated cation. It is possible that a more significant absorption of potassium would result if all of the potassium in the absorption solution were present in a form common in fertilizer materials, for example, KCl.

If it is considered that a base exchange capacity of 4.5 m.e. per 100 gms (as an example for the Coastal Plains soils) is equivalent to 4000 pounds per acre of K_2O if fully saturated with K, then it will be realized that a solution supplying a concentration of K equivalent to only 400 pounds per acre of K_2O will replace only the more dissociated ions in the base exchange complex, principally hydrogen. Removal of K from the solution will be limited to equilibrium exchanges of K^+ ion in the external solution with the dissociated ions in the micelle atmosphere. This exchange could hardly be expected to reflect fixation capacity of the soil for potassium, because localized concentrations in the soil solution resulting from fertilizer application would exceed the concentration in this absorption solution many times.

In this connection it should be stated that the absorption solution employed by Purvis (41) on the heavily fertilized Coastal Plains soils at the Virginia Truck Experiment Station contained 241 ppm (964 pounds per acre) of K_2O. Obviously the solution used in the present study was too weak with respect to potassium to give comparable results on the less heavily fertilized general farming soils of the Coastal Plains area. The same conclusion would apply even more patently to the heavier soils of the Limestone Valley region where fertilization rates are generally even lighter than on the soils used for general farming in Southeastern Virginia (53).

The concentration of P_2O_5 in the weaker absorption solution used in this study was nearly four times greater than the concentration in the solution used by Purvis (4.6 ppm, or 18 pounds per acre). The absorption values for P_2O_5 in Table 99 indicate that the 64 pound-per-acre solution at least approached the range necessary to satisfy the needs of these Coastal Plains soils with the highest reversion capacities.

The higher range of absorption values dealt with here for P_2O_5 as compared with the values secured by Purvis are probably due, to a considerable extent, to the increased absorption of the associated K^+ ion resulting from its dehydration by the alcohol. However, absorption would be expected to be greater on soils with a history of lower rates of fertilization than the truck soils studied by Purvis. Even greater absorption would be expected (and was obtained) on the heavy soils of the Shenandoah Valley.

Absorption procedures are doubtless of significant potential value for estimating the expected efficiency of phosphate and potash fertilizer applications on specific crops. However, their practical application will probably be limited to cropping programs that involve heavy rates of fertilization, and to high value crops that require large supplies of readily available forms of these two nutrients.

In general cropping programs built around grain and forage crops, fertilization must be considered as supplementary to the supplying capacity of the soil. Efficient crop production must depend upon legumes and similar crops with strong feeding power for potash and the more difficultly available forms of phosphorus to make maximum use of the soil supplying capacity for these nutrients over the period of the rotation (49). Soil management, liming, and fertilization practices must conform to the needs of these plants if they are to exert their maximum benefits.

Under these conditions, the information provided by extraction techniques concerning the supplies of available potash and of acid soluble and adsorbed phosphate will be of more pertinent value than the fixing capacity, which may exceed the available soil supplies several times.

If further work is undertaken to correlate absorption of P_2O_5 and K_2O from solution with crop response to fertilization, the following suggestions are made in the light of experiences encountered in the study reported here:

1. Phosphate and potash should be supplied in the solution (or solutions) in separate compounds, not as associated ions, to eliminate the effect of absorption of one ion on the absorption of the other. Probably both nutrients should be supplied in forms common in the fertilizer materials normally used.

2. Concentrations of both ions in the absorption solution

should probably approximate concentrations actually built up in localized areas in the soil solution by rates and placements of fertilizers normally used in the cropping systems and on the crops with which correlation is to be made.

3. Some means of clearing suspended soil materials from the filtrate, - other than by the addition of alcohol, - should be used. Activated carbon is suggested. Or it is possible that an increase in the concentrations of the components of the absorption solution, particularly the K^+ ion, as suggested under 2 above, will result in clear filtrates.

PART IV

CORRELATION OF FIELD AND LABORATORY DATA

A. CORRELATION OF RAPID SOIL TESTS WITH PREVIOUS FERTILIZER TREATMENTS

In the correlation of rapid soil tests with previous fertilizer treatments, the principle objectives have been the following:

a. To determine whether or not there are any differences in the ability of the various extracting solutions to detect residual accumulations of the different nutrients which may have resulted from previous fertilization.

b. To determine, by comparison with supplemental yield data, whether the test values for the various nutrients, with the testing procedures that were used, fall in a range that can be correlated with crop response to fertilization.

c. To assign tentative interpretative ranges to the test values secured with the different extracting solutions. Where the supplemental yield data have indicated good response to a particular nutrient, the test values for plots that have not received applications of the nutrient in the past have been interpreted as "low." Where response was moderate, a "medium" interpretation was given. A "high" interpretation was applied to test values where fertilizer applications failed to increase yields above plots to which none of the nutrient had been applied.

1. Potassium: *

Tables 4 and 5, pp. 33-35:

In Table 4 are cited soil test data for the Old Rotation experiment at Blacksburg on plots which had received no fertilizer (except 1 ton per acre of dolomitic limestone every four years) during 28 years of a 4-year rotation of corn, wheat, clover and clover-timothy. The fertilizer treatments listed were applied on corn during the crop year after the soil samples were taken. The yield and plant tissue test data in Table 5 represent the first fertilized crop on these plots.

The soil test data for potassium are remarkably uniform for all extractants. The test values probably represent the basal potassium supplying power of this Dunmore silt loam. The response of corn levels off at 72 pounds K_2O per acre. However, nitrogen is the first limiting factor, as is indicated by the August 20 tissue tests. Had supplemental nitrogen been supplied as a side-dressing later in the season, additional response to potassium on these plots could have been expected (45, 34).

Tables 6 and 7, pp. 36-37:

All extractants except Bray's reveal accumulation of potash following the 200 pound application of K_2O. Morgan's and Hester II also reflect accumulation following 100 pounds per acre. Soil tests following other rates of K_2O are erratic. Considering yield data

* Note: The data for K_2O with Thornton's potassium extractant is not considered in this discussion (see p. 134).

(Table 7), it can be said that no response would be expected on plots testing more than 280 pounds K_2O with Morgan's, or 210 pounds with Hester I and II.

Tables 8 and 9, pp. 38-41:

The results here follow closely those shown in Tables 6 and 7, and much the same conclusions may be drawn. All three crops in this rotation responded to 60 to 100 pounds per acre of K_2O. A low to medium interpretation would have to be made of test values for the plots which have received no potash. The maximum test values on all plots with Bray's solution suggest that soil test values higher than 400 pounds per acre with this extractant may be significant in crop response on some of the heavier soils in Virginia. In such cases, the extracts should have been diluted to obtain readings in this higher range.

Tables 10 and 11, pp. 42-45:

In Table 10, only the tests with Bray's and Morgan's solutions reflect accumulations from the 100- and 200-pound applications of K_2O. The increasing corn yields up to 60 pounds K_2O indicate that these soil test values are in a range significant to crop response.

There is no correlation with previous treatment in the potassium data in Table 11. The author is inclined to question the accuracy of the determinations. Accumulations are indicated by the P_2O_5 data, so accumulations of K_2O would have been expected.

Tables 12 and 13, pp. 46-48:

Considering yields, plant tissue test data, and leaf symptoms, potash must be considered moderately limiting on all these plots, and the soil tests would have to be so interpreted. No accumulations of potash would be expected from these rates of application at the yield levels encountered on all fertilized plots. The fact that nearly all of the K_2O values for Bray's solution are in the upper half of the reading range (see Table 38, p. 126) further supports the conclusion that the extract with Bray's solution should be diluted to give a significant range of readings on Dunmore silt loam and similar heavy soils. This is probably true also of Morgan's extractant, although less dilution would be necessary.

Tables 14 and 15, pp. 49-52:

The increases in yields of wheat and clover following potassium fertilization on these plots indicate that the soil test values represent medium to low levels of K_2O in the soil. Again the readings with Bray's and Morgan's solutions are generally higher in the reading range for these extractants than is compatible with a limiting potash interpretation.

Tables 16 and 17, pp. 53-55:

At the yield levels indicated in Table 17, some accumulation of K_2O would be expected from the 40- and 60-pound applications of potash. Only Bray's and Morgan's solutions reflect this increase in the soil supply, and then only on the limed plots. The responses to potash on the limed plots indicate that these soils test values must be interpreted as deficient.

Tables 18 and 19, pp. 56-59:

In Table 18, none of the extractants reveal accumulations from the 40- or 60-pound applications of K_2O. In Table 19, however, Bray's and Morgan's solutions definitely indicate a build-up in the level of soil potassium on both limed and unlimed plots.

Tables 20 and 21, pp. 60-63:

On this Granville sandy loam, low in both mineral and organic colloids, very little accumulation of K_2O from year to year would be expected, and none is indicated by any of the extractants. The increases in yields and quality of tobacco from applications up to 160 pounds per acre of K_2O make it necessary to interpret all soil test values as low.

Tables 22 and 23, pp. 64-66:

None of the extractants show any accumulations of K_2O from applications up to 200 pounds per acre of potash. The yield and tissue test data show no response to potash. Soil test values must be interpreted as high with regard to corn. Extremely low readings must be considered in error.

Table 24, pp. 67-68:

A similar interpretation must be made of the data here as in Tables 22 and 23. The K_2O values for Morgan's solution are at variance with those for the other solutions, but their accuracy in this case is questionable.

Tables 25, 26, 27, pp. 69-74:

No differential potassium treatments were involved in this experiment.

Conclusions from correlation of potassium tests with previous fertilizer treatment:

a. It appears that crop response to potash fertilization may be expected on some of the heavier soils in Virginia which give tests for K_2O higher than 400 pounds per acre with Bray's extractant. The reading range (p. 126) permitted by the testing procedure that was used does not extend above 400 pounds per acre. A wider soil-to-solution ratio should be used with Bray's solution on such soils; or the reading range maybe extended by diluting the extract.

b. Dilution of extracts or a somewhat wider soil-to-solution ratio is also indicated for Morgan's solution.

c. If the extracting procedure were modified as indicated above, it would seem that Bray's solution and Morgan's solution would permit a wider range of soil test values to be covered than either Hester I or II. This would allow a more accurate correlation with crop response on the heavier soils.

d. On the basis of residual soil test values and crop response, the following values for K_2O may be tentatively assigned high, medium and low interpretations for general field crops:

Extractant	Soil type	High	Medium	Low
Bray	Dunmore	280-400	160-240	40-120
	Berks	280-400	--------	-------
Morgan	Dunmore	280-400	160-240	40-120
	Berks	280-400	--------	-------
	Sassafras	160-400	--------	-------
Hester I and Hester II	Dunmore	210-300	90-180	30-60
	Berks	180-300	-------	------
	Sassafras	120-300	-------	------

2. Phosphorus:

Tables 4 and 5, pp. 33-35:

As with potash, the P_2O_5 values on these plots all represent depleted levels of available phosphorus. The values for each extractant are remarkably uniform.

Tables 6 and 7, pp. 36-37:

Residual accumulations of P_2O_5 are revealed by all four extractants. However, the values on plots that received no phosphate are lower than the yield and plant tissue test data would suggest. Moderate supplies of available phosphate which were not removed by any of the extractants must have been present in adsorbed form.

Tables 8 and 9, pp. 38-41:

No residual accumulations are shown by the data in Table 8, but in Table 9 marked accumulations are disclosed by all extractants following repeated applications of 120 pounds of P_2O_5. The limited response of wheat and clover to phosphate shows that moderate supplies of available P_2O_5 are present. Again these are not revealed by any of the extractants.

Tables 10 and 11, pp. 42-45:

Accumulations of P_2O_5 following heavy applications of phosphate are revealed by all extractants in Table 11. Greater accumulations are shown by Morgan's, Hester I and Hester II than by Thornton's. This would indicate accumulation in adsorbed form. This conclusion is further supported by the low recovery of P_2O_5 with Thornton's solution in Table 10. Response of corn to phosphate fertilization points to medium supplies of phosphorus on untreated plots. The soil tests are generally low for such an interpretation. The response of wheat in Table 11 is more in line with the phosphate test on the plots which have not received potash.

Tables 12 and 13, pp. 46-48:

Very little accumulation of P_2O_5 would be expected from these rates of application at the yield levels involved. None is indicated by any of the extractants. The response of corn to phosphate, as well as the plant tissue tests, indicate that the level of available P_2O_5 is low. The soil test values are in line with such an interpretation.

Tables 14 and 15, pp. 49-52:

The wide range of values for P_2O_5 with Thornton's extractant are probably in error. Otherwise, no accumulations are revealed, and none would be expected. The readings are in keeping with a "low" interpretation, based on the response of wheat and clover to applications of phosphate.

Tables 16 and 17, pp. 53-55:

No clear cut build-up of P_2O_5 is shown by any of the extractants. The yield data and the July 8 plant tissue test data supports an interpretation of the soil tests as low.

Tables 18 and 19, pp. 56-59:

The same deductions may be made here for wheat and clover as were made for corn in Tables 16 and 17.

Tables 20 and 21, pp. 60-63:

Residual build-up of phosphorus is shown by all extractants, following application of 80 to 120 pounds per acre. The response of tobacco to phosphate makes it necessary to consider soil test values on plots receiving no phosphate as being low in interpretation for tobacco.

Tables 22 and 23, pp. 64-66:

The data appears to be erratic, although accumulations are indicated by all extractants following 60- and 120-pound applications of phosphate. Yield data and tissue tests point to nitrogen as a first limiting factor in response to phosphorus. Magnesium is also limiting on several plots, as is shown by soil tests and leaf symptoms. Soil tests for P_2O_5 on the check plot must be interpreted as low for corn on Sassafras sandy loam.

Table 24, pp. 67-68:

Build-up of P_2O_5 is shown, consistently, only by Thornton's extractant and Hester II. It might be deduced from this that phosphorus is being tied up in acid-soluble form, - as theoretically would be the case on a sandy loam. Clover yields were limited by a shortage of magnesium and no response to phosphate was obtained. Soil tests for P_2O_5 on the plots which had not received phosphate would certainly have to be considered low for clover.

Tables 25, 26, 27, pp. 69-74:

No differential phosphate treatments were involved in this experiment. The lime treatments did not materially affect soil tests for P_2O_5.

Conclusions from correlations of phosphorus tests with previous fertilizer treatments:

a. The reading range (p. 126) permitted by the testing procedure was sufficient to cover all soil test values encountered, even where heavy applications of phosphate had resulted in very material increases in soluble soil phosphorus.

b. Correlations between soil tests for P_2O_5 and crop response to phosphate were inconsistent. On the heavier soils, the inconsistencies were probably attributable to supplies of adsorbed phosphorus which were not revealed by any of the extractants. No tentative interpretations of soil tests by categories of response could be made.

3. Calcium and magnesium:

Tables 8 and 9, pp. 38-41:

The magnesium tests on many of these plots are low. It is possible that the response of both wheat and clover to phosphate and potash was limited by the short supply of magnesium. There were no leaf symptoms to support this conclusion, however.

Table 12, p. 47:

No satisfactory correlation exists here between lime treatments and soil tests for calcium or magnesium.

Table 14, p. 50:

Calcium tests on limed plots are generally much higher than on the unlimed plots with all extractants except Hester II. The potential sensitivity of the calcium test is thus borne out. The fact that several tests appear to be considerably out of line, make it evident that laboratory manipulations were not always carefully carried out, and this factor may be credited with giving rise to much of the erratic variability of the calcium data throughout this investigation. There is no correlation here between liming and tests for magnesium.

Table 15, p. 52:

Here the calcium tests in several cases bear a reverse relation to liming history. Again the accuracy of the determinations must be questioned.

No differences in magnesium values have resulted from liming on any of the plots for which data has been cited in Tables 12, 14 and 15. This does not necessarily suggest that the magnesium test has failed to disclose variations in the soil supply of magnesium. If a high-calcium liming material had been used, no appreciable accumulation of magnesium would have occurred. No information is available as to the nature of the lime that was actually used.

Table 16, p. 54:

Although the data is vatiable, all extractants except Hester II reveal an appreciable build-up of soil calcium following the application of lime. The increase in soil magnesium following lime shows up very markedly with all extracting solutions. The low magnesium values on several of the unlimed plots might be interpreted as indicating that an inadequate supply of magnesium limited response of corn to both phosphate and potash. Response to both was much greater on the plots which received lime.

Table 18, p. 57:

Bray's solution and Hester I both give higher values for calcium after liming. All extractants give sharply increased tests for magnesium. Magnesium tests without lime are rather low. This may account in part for lower response to phosphate and potash on these plots than on the limed plots.

Table 19, p. 59:

Consistent increases in both calcium and magnesium following the application of lime are revealed by all extracting solutions. Here again the very low magnesium tests point to magnesium as a first limiting factor in response to phosphate and potash on the unlimed plots.

Tables 22 and 23, pp. 64-66:

No previous lime treatments are involved in this experiment. However, leaf deficiency symptoms support low soil test values in pointing to magnesium as a first limiting factor in crop response at this location. The data and observations from this experiment are cited in support of tentative conclusions drawn in the discussion on magnesium with reference to Tables 8, 9, 16, 18 and 19.

Table 24, pp. 67-68:

Here again leaf symptoms support an interpretation of soil test values for magnesium as being deficient.

The limited response to moderate increments of phosphate and potash in this experiment is similar to others where a similar interpretation was made regarding low soil tests for magnesium.

Tables 25, 26, and 27, pp. 69-74:

This rate of liming experiment should have been ideal for calibrating the calcium test for Coastal Plains soils. However, there is very little correlation between the lime application and the test for calcium. Faulty laboratory technique is indicated.

The magnesium tests with all extractants follow quite consistently the schedule of rates of application of the oyster shell. The response of corn, cotton and peanuts to increasing increments of the liming material levels off at the 1500 pound application. It is of interest to compare the magnesium test for the plots receiving 1200 and 1500 pounds of oyster shell here with the tests tentatively interpreted as limiting in Tables 8, 9, 16, 18, 19, 22, 23 and 24. It will be found that in no case do they exceed the following values:

Bray ———— 120

Morgan ——— 120

Hester I —— 90

Hester II —— 90

These values may be tentatively taken as representing the approximate dividing line between limiting and adequate supplies of magnesium. They must be considered only general limits. There is insufficient data to attempt to differentiate between the magnesium requirements of the different soil provinces.

<u>Conclusions from correlation of calcium and magnesium tests with previous applications of lime</u>:

a. In numerous instances extreme variability in calcium tests pointed to careless laboratory technique.

b. At several locations, all extractants except Hester II definitely revealed calcium increases after liming. Thus the potential sensitivity of the calcium test is indicated, although further modification of the testing procedure and reagents appears necessary.

c. All extractants appeared to be quite sensitive to magnesium accumulations after applications of lime.

d. The range of reading values permitted by the testing procedures used (p. 126) was apparently adequate for all situations encountered, - for both calcium and magnesium.

e. The data provided no criteria for subjecting soil test values for calcium to tentative interpretation as high, low or medium.

f. In several instances magnesium was indicated to be the first limiting factor in crop response to additions of the major nutrients. Tentative limiting levels of magnesium were proposed for the four extracting solutions.

B. HIGH-LOW-MEDIUM INTERPRETATION OF RAPID SOIL TESTS AND YIELD DATA INVOLVING CROP RESPONSE TO CURRENT FERTILIZER APPLICATIONS.

During the summer of 1941 several experiments were conducted at a number of locations to determine the response of several crops to various levels of phosphate and potash fertilization. Soil samples had been composited from each location in the spring prior to the application of the fertilizer treatments. The rapid soil test values for these samples and the corresponding yield data are tabulated in Tables 28 through 85.

In Tables 101 through 110 the rapid soil test values for phosphate and potash from these experiments are listed by categories of the type of crop response shown at each location.

It was reasoned that the value of increased crop yields for each increment of a nutrient should return the cost of the nutrient plus 20% for interest, cost of application and increased crop handling costs, in order to be profitable. If no profitable returns were gotten at any level of phosphate or potash application, adequate soil supplies were indicated, and the interpretation of soil test values would be "high." Profitable returns for the first increment and none for additional increments indicated moderate soil supplies, and the interpretation of soil test values would be "medium." A "low" interpretation would be called for when profitable increases in yields were obtained for increments in addition to the first.

In applying the above line of reasoning to the data, response determinations were limited to plots which received identical applications of nutrients other than the one for which response was being determined. Average market values were assigned to crops and fertilizer constituents to arrive at the profitability of returns.

1. Potassium on corn - Coastal Plains Soils:

There were no locations covered by the data in Table 101 where a "high" interpretation could be made. Plant tissue tests indicate that, in most cases, responses to fertilization were limited by nitrogen as the first deficient nutrient. Magnesium tests were very low at most locations, which also would have imposed a ceiling on corn yields. Thus it is felt that a number of "medium" tests would have been moved over into the "low" column had nitrogen and magnesium been present in more adequate supply.

These factors were considered in deducing the tentative interpretative values cited at the bottom of Table 101.

Table 101 - Rapid soil test values for K_2O listed by categories* of profitable crop response to fertilization as determined by field experiments. Corn - Coastal Plains Soils.

Table (Basic Data)	Soil type	Bray			Morgan			Hester I			Hester II			Purvis		
		High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low
28-29	Onslow			80			80			30			30			200
	fine s.l.			80			80			30			30			200
34-35	Onslow		120			80			60			60			160	
	v. f. s. l.		120			80			60			60			200	
32-33	Lenoir		160			120			60			60			200	
	f. s. l.		160			120			60			60			200	
30-31	Norfolk		120			120			90			60			120	
	f. s. l.		80			80			60			60			120	
36-37	Norfolk		80			80			60			60			120	
	f. s. l.		120			80			60			30			120	
38-39	Norfolk		80			80			60			15			160	
	s. l.		120			120			120			50			160	
Tentative interpretative values			120 plus	None to 120		120 plus	None to 120		90 plus	None to 90		90 plus	None to 90		120 to 200	200 plus

* Criteria for establishing categories:
High - Non-profitable response to first increment of K_2O
Med. - Profitable response to first increment only
Low - Profitable response beyond first increment
The following market values were assumed:
Corn - $1.40 per bushel
K_2O - $1.26 per 18-pound increment (7¢ per pound)

2. Potassium on cotton -- Coastal Plains Soils:

Only two locations were sampled in getting the data cited in Table 102. Profitable increases in yield of seed cotton were obtained at both locations, beyond the response for the first thirty-pound increment of K_2O. Plant tissue tests at full bloom indicated a deficiency of nitrogen in both trials. Magnesium soil tests were also low. It seems safe to conclude that all soil tests for K_2O indicate low levels as far as cotton nutrition is concerned. One reading with Hester II for 150 pounds per acre was disregarded in setting forth tentative interpretative values. It is possible that further work might point to a demarcation between low and medium readings higher than 120 pounds per acre for Hester II. If so, however, it would probably also apply to Hester I and Morgan's solution.

The relatively low absorption of potash from the Purvis absorption solution (400 pound per acre equivalent in original solution) does not logically lend itself to an interpretation of low potash availability (or of high soil requirement for potash).

Table 102 - Rapid soil test values for K_2O listed by categories* of profitable crop response to fertilization as determined by field experiments. Cotton - Coastal Plains Soils.

Table (basic data)	Soil type	Bray			Morgan			Hester I			Hester II			Purvis		
		High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low
40-41	Norfolk f.s.l.			160 160			120 120			120 120			120 150			120 80
42-43	Norfolk f.s.l.			160 80			120 40			90 30			90 30			120 60
Tentative interpretative values			160 plus	None to 160		120 plus	None to 120		120 plus	None to 120		120 plus	None to 120		—	—

* Criteria for establishing categories:
- High - Non-profitable response to first increment of K_2O
- Med. - Profitable response to first increment <u>only</u>
- Low - Profitable response beyond first increment

The following market values were assumed:
- Seed cotton - 4¢ per pound (12¢ per pound for lint)
- K_2O - \$2.10 per 30-pound increment (7¢ per pound)

3. Potassium on Peanuts - Coastal Plains Soils:

Only one of the soil situations for which data is cited in Table 103 gave profitable increases in peanut yields beyond the first 24-pound increment of K_2O. An unfavorable soil reaction (pH 5.2-5.9) on the Norfolk fine sand as shown in Tables 48 and 49 probably limited response on these plots, so that the corresponding soil test values could very well be interpreted as low for potash.

In visual reading of the potash test there will always be borderline tests which may be read on one side or the other of the break-off point between "low" and "medium" or "medium" and "high." Interpretative values for potash in Table 103 have been developed in such a manner as to bring the several inconsistent readings in the "medium" column into agreement with the tentative break-off value within the limits of the difference between adjacent standards (Table 3, p. 29). At the same time an attempt was made to keep these critical response levels between "medium" and "low" in line with the average extracting power of the different extractants (Table 89, p. 135).

Again the data for Purvis' absorption solution does not fit the interpretation required by crop response.

Table 103 - Rapid soil test values for K_2O listed by categories* of profitable crop response to fertilization as determined by field experiments. Peanuts - Coastal Plains soils.

Table (Basic Data)	Soil type	Bray			Morgan			Hester I			Hester II			Purvis		
		High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low
46-47	Onslow f.s.l.			80 80			40 80			60 60			30 60			160 120
44-45	Norfolk f.s.l.		120 120			80 80			90 120			90 120			160 120	
48-49	Norfolk f.s.		80 80			80 80			90 90			90 90			120 120	
50-51	Norfolk f.s.l.		120 120			80 80			60 90			60 90			160 120	
52-53	Norfolk s.l.		200 200			160 160			150 150			150 150			160 160	
Tentative interpretative values			120 plus	None to 120		120 plus	None to 120		90 plus	None to 90		90 plus	None to 90		---	---

* Criteria for establishing categories:

High - Non-profitable response to first increment of K_2O
Med. - Profitable response to first increment <u>only</u>
Low - Profitable response beyond first increment

The following market values were assumed:

Peanuts - 4¢ per pound
K_2O - $1.68 per 24-pound increment (7¢ per pound)

4. Potassium on corn - Limestone Valley Soils:

Extremely dry weather during much of the growing season resulted in erratic response to potash in several of the corn fertilization trials from which data is tabulated in Table 104. The suggested interpretative values are almost wholly synthetic. In practice, the data from numerous experiments over a period of years would have to be evaluated and tabulated in the manner shown before dependable interpretative ranges for a high-low-medium interpretation could be developed.

Table 104 - Rapid soil test values for K_2O listed by categories* of profitable response to fertilization as determined by field experiments. Corn - Limestone Valley Soils.

Table (Basic Data)	Soil type	Bray			Morgan			Hester I			Hester II			Purvis		
		High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low
54-55	Frederick silt loam		160 120			120 80			90 60			60 60			600 600	
56-57	Frederick silt loam			280 160			160 80			120 60			120 60			680 720
58-59	Hagerstown stony c.l.	280 200			160 120			90 105			90 105			560 560		
60-61	Frederick silt loam			240 280			240 240			150 150			150 150			400 400
62-63	Frederick silt loam		360 160			240 160			150 120			120 120			400 400	
64-65	Frederick silt loam			40			40			30			30			
66-67	Hagerstown clay loam			40			40			30			30			
68-69	Holston f.s.l.			120			40			30			30			
70-71	Jefferson f.s.l.			40			40			30			30			
72-73	Elk loam			160			40			30			30			
Tentative interpretative values			280 plus	40 to 280		240 plus	40 to 240		150 plus	30 to 150		150 plus	30 to 150	---	---	---

* Criteria for establishing categories:
High - Non-profitable response to first increment of K_2O
Med. - Profitable response to first increment <u>only</u>
Low — Profitable response beyond first increment
The following market values were assumed:
Corn - $1.40 per bushel
K_2O - $1.26 per 18-pound increment (7¢ per pound)

5. Potassium on wheat - Limestone Valley Soils:

The data in Table 105 was derived from a fertilizer trial, involving only 12-pound increments of K_2O. It is felt that a more useful calibration for wheat could be developed if eighteen-pound or twenty-four-pound increments were used.

The tentative low and medium values for Hester I ignore the fact that at two locations test values of 270 pounds per acre of K_2O were placed in the low column. It was necessary to do so to keep these values in line with the other extracting solutions and their comparative extracting powers.

Table 105 - Rapid soil test values for K_2O listed by categories* of profitable response to fertilization as determined by field experiments. Wheat - Limestone Valley Soils.

Table (Basic Data)	Soil type	Bray			Morgan			Hester I			Hester II		
		High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low
74-75	Berks silt loam			160			160			60			30
76-77	Berks silt loam			280			200			270			210
78-79	Elk silt loam			240			240			270			150
80-81	Jefferson f.s.l.			80			160			60			30
82-83	Hagerstown clay loam			240			40			30			30
84-85	Frederick silt loam			40			40			30			30
Tentative interpretative values			280 plus	40 to 280		240 plus	40 to 240		210 plus	30 to 210		210 plus	30 to 210

*Criteria for establishing categories:

High - Non-profitable response to first increment of K_2O

Med. - Profitable response to first increment only.

Low - Profitable response beyond first increment

The following market values were assumed:

Wheat - $1.75 per bushel

K_2O - $ .84 per 12-pound increment (7¢ per pound)

6. Phosphate on corn - Coastal Plains Soils:

Plant tissue tests at several of the locations from which data was secured for Table 106 indicate that nitrogen was the first limiting factor in crop growth. Severe magnesium deficiency symptoms showed up at two locations, which supports soil tests in pointing to magnesium as the first limiting factor where nitrogen was not. Had these deficiencies been taken care of, it is very probable that the corn on all of these plots would have responded to additional increments of phosphate. Thus all of the soil test values would have been shifted over into the "low" column.

The above premise was applied in arriving at interpretative values in Table 106. At the same time these values were modified to keep them in line with the average relative extracting powers of the extractants as listed in Table 89, p. 135.

It will be seen that the wide divergency in soil test values for Thornton's solution makes it of dubious value for diagnosing the phosphate requirements of crops on the Coastal Plains soils. The acid soluble forms of phosphorus measured by it are apparently not entirely significant in crop growth.

Table 106 - Rapid soil test values for P_2O_5 listed by categories* of profitable crop response to fertilization as determined by field experiments. Corn - Coastal Plains Soils.

Table (Basic Data)	Soil type	Morgan			Hester I			Hester II			Thornton			Purvis		
		High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low
28-29	Onslow		16			8			16			48			48	
	f.s.l.		24			8			16			32			48	
34-35	Onslow		8			3			32			64			60	
	v.f.s.l.		8			3			32			64			62	
32-33	Lenoir			16			3			16			64			62
	f.s.l.			16			3			16			64			62
30-31	Norfolk		16			32			24			80			60	
	f.s.l.		24			16			16			48			60	
36-37	Norfolk			16			16			48			96			48
	f.s.l.			16			32			48			128			48
38-39	Norfolk		16			16			24			96			48	
	s. l.		16			16			16			80			60	
Tentative interpretative values			24 plus	None to 24		32 plus	None to 32		32 plus	None to 32		48 plus	None to 48		Less than 48	48 to 64

* Criteria for establishing categories:

High - Non-profitable response to first increment of P_2O_5

Med. - Profitable response to first increment only

Low - Profitable response beyond first increment

The following market values were assumed:

Corn - $1.40 per bushel

P_2O_5 - $1.26 per 18-pound increment (7¢ per pound)

7. Phosphate on cotton - Coastal Plains Soils:

Here again plant tissue tests point to nitrogen as limiting and soil tests indicate an inadequate supply of magnesium. Greater response to phosphate would probably have been gotten had these other nutrients been more amply available. This would have thrown all soil tests for P_2O_5 over into the "low" column. Interpretative values were deduced accordingly.

One extremely high reading with Thornton's extractant is obviously out of line with actual crop response. Again the inapplicability of this extractant to these soils is borne out.

The low absorption of P_2O_5 from Purvis' solution at the first location cannot be interpreted in terms of the high soil requirement indicated by crop response.

Table 107 - Rapid soil test values for P_2O_5 listed by categories* of profitable crop response to fertilization as determined by field experiments. Cotton - Coastal Plains Soils.

Table (basic data)	Soil type	Morgan			Hester I			Hester II			Thornton			Purvis		
		High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low
40-41	Norfolk f.s.l.			8 8			16 8			16 16			8 8			40 40
42-43	Norfolk f.s.l.		24 16			16 8			24 8			96 48			120 160	
Tentative interpretative values			24 plus	None to 24		24 plus	None to 24		32 plus	None to 32		48 plus	None to 48		—	—

*Criteria for establishing categories:
- High - Non-profitable response to first increment of P_2O_5
- Med. - Profitable response to first increment <u>only</u>
- Low - Profitable response beyond first increment

The following market values were assumed:
- Seed cotton - 4¢ per pound (12¢ per pound for lint)
- P_2O_5 - $1.75 per 25-pound increment (7¢ per pound)

8. Phosphate on peanuts - Coastal Plains Soils:

The pH of the Onslow fine sandy loam (Tables 46-47) was so low (pH 5.3-5.5) that it probably limited response of peanuts to phosphate. Also the magnesium soil test was very low. Dolomitic limestone was applied with the fertilizer at the rate of 400 pounds to one ton of fertilizer. However, the availability of the magnesium applied as the carbonate on the surface was possibly not adequate to supply crop needs. Had these basic soil requirements been satisfied, the response to phosphate on these plots would reasonably have been such as to allow a "low" interpretation of the soil tests. Thus all soil test values in Table 108 can be given an interpretation as "low" for peanuts.

The fact that four values for Thornton's solution are at the top of the reading range (Table 88, p. 126) makes them meaningless if a "low" interpretation must be applied to them, and underscores the inapplicability of this extractant to Coastal Plains soils.

Table 108 - Rapid soil test values for P_2O_5 listed by categories* of profitable crop response to fertilization as determined by field experiments. Peanuts - Coastal Plains Soils.

Table (Basic Data)	Soil type	Morgan			Hester I			Hester II			Thornton			Purvis		
		High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low
46-47	Onslow f.s.l.		16 16			16 16			8 8			24 24			60 60	
44-45	Norfolk f.s.l.			16 24			16 32			16 32			8 16			16 8
48-49	Norfolk f.s.			8 8			8 16			16 16			8 16			40 32
50-51	Norfolk f.s.l.			32 32			64 64			64 48			128 128			32 32
52-53	Norfolk s.l.			32 32			64 64			48 48			128 128			40 40
Tentative interpretative values			32 plus	None to 32		64 plus	None to 64		64 plus	None to 64		---	---		---	---

* Criteria for establishing categories:
- High - Non-profitable response to first increment of P_2O_5
- Med. - Profitable response to first increment only
- Low - Profitable response beyond first increment

The following market values were assumed:
- Peanuts - 4¢ per pound
- P_2O_5 - $1.68 per 24-pound increment (7¢ per pound)

9. Phosphate on corn - Limestone Valley Soils:

The data in Table 109 for corn on Limestone Valley soil types illustrates the behavior of these extractants on the heavy soils. The pH's are available for the first five locations in the table. The first two locations were near neutral and high in calcium. The recovery of P_2O_5 with Morgan's was low as compared with Hester I. This was due to the relatively high pH of the extractant, which, augmented by the high pH and high calcium contents of the soils, suppressed the solubility of acid-soluble calcium phosphate. The recovery with Thornton's solution was low as a result of its lack of buffering, which resulted in reprecipitation of dissolved phosphorus as calcium phosphate. Inadequate buffering of Hester II resulted in lower recovery than with Hester I, although the recovery was somewhat greater than with either Morgan's or Thornton's extractants. Low pH, combined with greater buffering, resulted in greater recovery with Hester I than with any of the other extractants on these two high lime soils (see Table 92, p. 143).

Apparently, some accumulation of phosphate as acid-soluble calcium phosphate had occurred on these two soils. The extent of its availability to the corn crop is to be questioned however, considering the responses which were gotten from fertilizer phosphorus.

The recovery with Morgan's solution was low compared with the other extractants at all locations listed in Table 109, regardless of pH, while the recovery with Hester I and Thornton's, in several instances, was fairly high. This would indicate that acid-soluble forms were predominant in the soil supplies of phosphorus. With the limited range of crop response covered by these trials, and in the absence of any exact data to distinguish between acid-soluble and adsorbed forms, this must remain a conjecture.

The effect of lime upon phosphorus recovery shown in Table 109 (and in Tables 94 and 95, pp. 146-147), as well as the unanswered question of the relative significance to crop nutrition of adsorbed and acid-soluble forms of soil phosphorus in these Mountain soils, do suggest the difficulties which stand in the way of arriving at a workable calibration for phosphorus on these soils, using any of the extractants that have been tried thus far.

Further basic research, using extractants capable of differentiating between the various forms of soil phosphorus, is indicated.

Table 109 - Rapid soil test values for P_2O_5 listed by categories* of profitable response to fertilization as determined by field experiments. Corn - Limestone Valley Soils.

Table (Basic Data)	Soil type	Morgan			Hester I			Hester II			Thornton			Purvis		
		High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low
54-55	Frederick s.l.			8			32			8			8			104
	pH 6.7			4			32			16			4			112
56-57	Frederick s.l.		16			48			8			4			124	
	pH 7.2		8			80			48			4			124	
58-59	Hagerstown st.			0			16			4			4			120
	c.l. pH 5.8			0			16			4			4			120
60-61	Frederick s.l.			4			8			4			8			126
	pH 5.9			4			4			4			8			128
62-63	Frederick s.l.			8			16			8			16			124
	pH 6.2			8			16			8			24			124
64-65	Frederick silt loam			8			16			12			16			
66-67	Hagerstown clay loam			8			12			16			16			
68-69	Holston fine sandy loam			8			16			16			32			
70-71	Jefferson f.s.l.			8			24			16			16			
72-73	Elk loam			16			16			32			16			
Tentative interpretative values			16 plus	None to 16		48 plus	None to 48		32 plus	None to 32		32 plus	None to 32			

* Criteria for establishing categories:

High - Non-profitable response to first increment of P_2O_5

Med. - Profitable response to first increment only

Low -- Profitable response beyond first increment

The following market values were assumed:

Corn - $1.40 per bushel

P_2O_5 - $1.26 per 18-pound increment (7¢ per pound)

10. Phosphate on wheat - Limestone Valley Soils:

The fluctuation in soil test values for Morgan's solution in Table 110 indicates more of a variation in soil supplies of adsorbed phosphorus than in the soils covered by Table 109. No data on soil acidity is available, but high calcium and magnesium tests at several locations indicate that suppressed solubility of acid-soluble phosphorus was the cause of several of the low readings with Morgan's, and that re-precipitation of dissolved phosphorus probably reduced recovery in several instances with both Thornton's solution and Hester II.

The fairly uniform readings for Hester I suggest that the low pH, intermediate buffering, and relatively high anion normality of this extractant give it somewhat greater versatility and make it more universally applicable to Virginia soil conditions than the other phosphorus extractants that were dealt with in this study. On the other hand, the low activity of the anion employed in it does make it of little value for revealing supplies of adsorbed phosphorus.

The performance of Hester I here suggests that a phosphorus extractant more applicable to the Limestone Valley soils should combine an anion, more active than the acetate ion, with the low pH, intermediate buffering, and moderately high anion normality of Hester I.

Table 110 - Rapid soil test values for P_2O_5 listed by categories* of profitable response to fertilization as determined by field experiments. Wheat - Limestone Valley Soils.

Table (Basic Data)	Soil type	Morgan			Hester I			Hester II			Thornton		
		High	Med.	Low	High	Med.	Low	High	Med.	Low	High	Med.	Low
74-75	Berks silt loam			8			16			16			8
76-77	Berks silt loam			8			12			8			8
78-79	Elk silt loam			32			32			24			16
80-81	Jefferson f.s.l.			16			24			16			32
82-83	Hagerstown clay loam			16			24			16			8
84-85	Frederick silt loam			8			24			16			16
Tentative interpretative values			32 plus	4 to 32		32 plus	4 to 32		24 plus	4 to 24		32 plus	4 to 32

* Criteria for establishing categories:

High - Non-profitable response to first increment of P_2O_5

Med. - Profitable response to first increment <u>only</u>

Low - Profitable response beyond first increment

The following market values were assumed:

Wheat - $1.75 per bushel

P_2O_5 - $2.52 per 36-pound increment (7¢ per pound)

11. Discussion:

No statistical limits could be set upon the interpretation of the data. That is probably the most serious weakness in this entire investigation. Also, the experiments with each crop failed to cover a sufficient range of crop response to do more than tentatively establish the critical response level between a "low" and a "medium" interpretation.

However, certain conclusions can be made, and the data does suggest certain considerations to be kept in mind in setting up a soil testing system and a system of soil test interpretation.

In the deduction of "high," "medium" and "low" interpretations for potash, Barber's (1) observation is borne out that Bray's sodium perchlorate extracts larger quantities of potash and thus gives a wider range of test values for calibration than the other extractants. Barber (1) also found that recovery by the various extractants is quite consistently proportional to their relative extracting powers, so that they all "achieve the same purpose in principle, differing only in degree." For a high-low-medium interpretation, it would appear that, for potash, any one of the four test solutions, - Bray, Morgan, Hester I or Hester II, - could be used with satisfaction. By the same token, Thornton's sodium nitrite, if used in accordance with the procedure as originally described (48), would very probably be satisfactory, and give only a little lower recovery than Bray's potassium extractant (see p. 134). Tentative potassium soil test values for "low" and "medium" interpretation have been set forth in Tables 101-105 for each extractant for several crops in the Coastal Plains and Limestone Valley provinces.

For the phosphorus extraction, the modified Thornton's 0.05 N HCl appears to be entirely inapplicable to either Coastal Plains or Limestone Valley soils. The same limitations would even more effectively rule out the 0.75 N HCl as originally described by Thornton (48).

Of the four phosphorus extractants tried, Hester I is probably more universally adaptable to varying Virginia soil conditions than any of the others. The influence of varying supplies of lime on the extraction of phosphorus by all four solutions, and the fact that none of them release adsorbed phosphorus very effectively made it difficult to arrive at a workable calibration for any general soil area. However, "low" and "medium" values have been suggested in Tables 106 to 110.

The data with Purvis' absorption solution for both phosphate and potash is not amenable to interpretation in terms of crop response.

In general, it may be observed that a high-low-medium interpretation permits only three basic recommendations for any crop: no fertilizer for a "high" reading, some for a "medium" reading, and more for "low." The actual rate of application to be recommended must be determined for each crop and soil area by field experiments and will necessarily have to be an average rate for the area. Adjustments for variations within the low and medium test ranges, if made at all, will depend upon the experience of the person making the recommendations and his familiarity with the soils and crops of the area. Even for the expert diagnostician, the interpretation of soil tests as high, medium or low will be little better than a guess, as is indicated, in the data in Tables 101 to 110, by the large number of borderline "either-or" readings around the critical response level between "low" and "medium."

The effect of low soil reaction and inadequate supplies of nitrogen and magnesium in setting static yield levels and limiting crop response to phosphate and potash is indicated all through the data. A high-low-medium interpretation makes no allowance for the existing productive potential of soils, which very often hinges upon limiting factors other than the major nutrients. It is much like attempting to make feeding recommendations for a dairy cow on the basis of the percentage protein in her stomach contents. Hereditary, environmental, and other factors may limit her response to increased protein, no matter how low the protein level in her stomach may be as a result of a low protein diet.

In dairy herd improvement work, the key to the optimum ration for any particular cow is that particular cow's current level of production. If it is a good cow and well-managed otherwise, addition of protein to a poor timothy hay ration will increase her production to the point where she can profitably utilize, not just more protein, but more total digestible nutrients. If it is a poor cow, the limiting hereditary factors must be corrected in her offspring by good breeding before a higher level of nutrition can be justified profit-wise.

A very similar concept is involved in the fertilization of soils for crop production. The first limiting factors in crop production very often are not revealed in rapid chemical soil tests. The tests are too frequently the only information the extension soils specialist has to base his recommendations on, - beyond the location and approximate soil type of the soil sample. Even if information pertaining to cropping and fertilization history, drainage, and other agronomic factors are available, the specialist must go beyond the high-low-medium interpretation of soil test values if he is to make recommendations that will result in the most effective utilization of fertilizer nutrients.

It sometimes happens that a first limiting factor is difficult to diagnose, or, if determined, may require a period of years to correct. In the meantime, the farmer must continue to make a living. To do so at the less than satisfactory yield levels imposed by a limiting factor, - poor soil structure, for example, - he must utilize the other factors of production, including fertilizer nutrients, with utmost efficiency. This may call for lower levels of fertilizer application than soil tests might indicate for a period of time until the first limiting factor can be corrected. Or again, on unusually productive farms, higher levels of fertilization may profitably be used than soil tests might indicate, because the soil tests were probably not calibrated by field experiments on the best farms in the area.

Thus, the high-low-medium interpretation allows for no systematic correlation between fertilizer recommendations based on rapid soil tests and the current capacity of a given field to produce. This correlation must be supplied by the specialist who interprets the readings, and it requires skill, experience, and thorough familiarity with the crops and soils being dealt with.

It would appear open to conjecture whether, in the high-low-medium interpretation of rapid soil test, it may not be the concept, rather than the inaccuracy of rapid testing procedures themselves, which has been the first limiting factor in their usefulness and more general acceptance.

C. INTERPRETATION ON THE BASIS OF SIMPLE RESPONSE OR NON-RESPONSE

The high-low-medium interpretation of soil tests requires that two critical response levels be determined by calibration studies, - one between "low" and "medium" readings and one between "medium" and "high." If the inaccuracy of rapid soil tests were responsible for their low predictability on a high-low-medium basis, then it is conceivable that a somewhat higher predictability might be gotten if only one critical response level were involved in the interpretation.

To check this possibility an attempt was made to correlate the same data on the basis of simple response or non-response. The correlation for P_2O_5 on corn on Coastal Plains Soils in Table 11 illustrates the procedure which was followed. The data for these six experiments permitted the use of fiducial limits in establishing response or non-response. The fields were separated into two groups, those which showed significant response to each of four rates of application of P_2O_5 and those which did not. The corresponding soil tests were averaged for each group. The critical level for response or non-response was taken as the mean of the average test values for responding and non-responding soils. This critical level is entered in the circle in the center of the response quadrant at the right of the table.

The number of soils in each group with soil test values <u>less</u> than the critical level were entered in the second and third quadrants, or to the <u>left</u> of the vertical axis. The number of soils with soil test values <u>greater</u> than the critical level were entered in the first and fourth quadrants, or to the right of the vertical axis.

For 100% predictability, the soil test values for all responding soils should be less than the critical level, and should appear in the second quadrant. Conversely, the values for non-responding soils should be greater than the critical value and appear in the fourth quadrant. Readings which were the same as the critical level were considered predictable.

The limited number of trials involved does not permit drawing any conclusions regarding the relative predictability of soil tests by the various extracting procedures from the predictabilities listed in Table 111. Some of the higher predictabilities are based on the fallacy of considering test values equal to the critical value as being accurately predictable. Actually, on the basis of chance, only 50% of such could be so considered.

However, Table 111 illustrates the procedure which was used in arriving at the predictabilities tabulated in Table 112. This procedure was applied to the same data that was used for the high-low-medium correlations in Tables 101 to 110. The two experiments with cotton were not included in Table 112 because they did not give a sufficient number of responses to give a reasonable critical response level.

The yield differences for the experiments with corn on Limestone Valley soils and peanuts on Coastal Pláins soils were not statistically significant. For these it was necessary to establish the level of response or non-response on the basis of the average increase in yield for each group of experiments. The locations where yield increases were greater than the average for the same crop at all locations on the same soil area were considered to be responding soils. Those where yield increases were less than average were considered non-responding soils.

The average predictabilities at the bottom of Table 112 are so near to 50% that they must be considered a function of chance rather than of any correlation between soil tests and crop response. Fairly good predictabilities for individual extractants can be observed with particular crops in both soil areas. However, these are based on such a limited number of responses as to lose all significance. Lawton (35), using a similar method of analyzing the data from 55 experiments (110 responses) with alfalfa in Michigan, found the accuracy of prediction of significant yield responses to be 60 to 80% for P_2O_5, and 50 to 65% for K_2O.

It would seem that the rapid soil tests that were used in the present correlation study are about equally unpredictable whether a high-low-medium interpretation is used, or an interpretation based on simple response or non-response.

Neither interpretation relates soil tests to existing production levels of individual fields. Nutrient supply is only one of many variable agronomic factors which determine crop yields. Even within an area comprising similar soil types, many of these factors vary independently of each other. It is felt that this fact makes it impossible to establish critical response levels for the major nutrients which can be applied to a whole area without regard to the capacities and limitations of individual fields.

If a 60 to 80% accuracy of prediction is to be the limit of efficiency of rapid soil tests interpreted by either of these concepts, then a qualified soils specialist can equal or better this performance by basing his recommendations simply on knowledge of soil type, pH, cropping and fertilization histories, drainage and a few other pertinent visual observations. This leaves for the soil tests merely the function of acting as a peg to hang fertilizer recommendations on after they have been formulated on wholly different premises.

The role of soil testing on this basis is as a propaganda instrument in an extension program geared to educating farmers into the acceptance of commercial fertilizers. This phase of soils extension has been carried out with distinction in most of the older agricultural areas of the country, as statistics on fertilizer sales in those areas prove conclusively (32). Unless the performance of rapid soil tests can be improved by refinements in testing procedures or by a more accurate interpretation of them, then it may be visualized that they might soon become a worn out tool.

Table 111 - Correlation of rapid soil tests for P_2O_5 with responding and non-responding fields of corn on Coastal Plains Soils.

Treatment Comparison	Extractant	Response Group	Yield Increases - *Bus. Basic Data Tables 29	31	33	35	37	39	Ave.	Soil Tests - P_2O_5 Basic Data Tables 28	30	32	34	36	38	Ave.	Response Prediction Quadrant	Predict-ability
2-6-6 over 2-0-6	Morgan	R	4.5	4.9		4.5			4.6	20	20		8			16	1 (16) 2	67%
		NR			0.5		-2.9	0.7	-1.7			16		16	16	16	1 3	
	Thornton	R	"	"		"			4.6	40	64		64			56	3 (74)	83%
		NR			"		"	"	-1.7			64		112	96	91	1 2	
	Hester I	R	"	"		"			4.6	8	24		3			12	2 (13) 1	67%
		NR			"		"	"	-1.7			3		24	16	14	1 2	
	Hester II	R	"	"		"			4.6	16	20		32			23	2 (26) 1	50%
		NR			"		"	"	-1.7			16		48	20	28	2 1	
2-12-6 over 2-0-6	Morgan	R		4.6	5.9		5.6	6.1	5.6		20	16		16	16	17	3 (16) 1	67%
		NR	3.9			3.6			3.8	20			8			14	1 1	
	Thornton	R		"	"		"	"	5.6		64	64		112	96	84	2 (68) 2	30%
		NR	"			"			3.8	40			64			52	2	
	Hester I	R		"	"		"	"	5.6		24	3		24	16	17	1 (12) 3	17%
		NR	"			"			3.8	8			3			6	2	
	Hester II	R		"	"		"	"	5.6		20	16		48	20	26	3 (25) 1	67%
		NR	"			"			3.8	16			32			24	1 1	
2-18-6 over 2-0-6	Morgan	R			6.4		7.1		6.8			16		16		16	2 (16)	83%
		NR	3.1	4.0		2.5		0.3	2.5	20	20		8		16	16	1 3	
	Thornton	R			"		"		6.8			64		112		88	1 (77) 1	30%
		NR	"	"		"		"	2.5	40	64		64		96	66	3 1	
	Hester I	R			"		"		6.8			3		24		14	1 (14) 1	50%
		NR	"	"		"		"	2.5	8	24		3		16	13	2 2	
	Hester II	R			"		"		6.8			16		48		32	1 (27) 1	30%
		NR	"	"		"		"	2.5	16	20		32		20	22	3 1	
2-24-6 over 2-0-6	Morgan	R			11.3		11.0		11.2			16		16		16	2 (16)	83%
		NR	2.2	3.1		1.6		1.3	2.1	20	20		8		16	16	1 3	
	Thornton	R			"		"		11.2			64		112		88	1 (77) 1	30%
		NR	"	"		"		"	2.1	40	64		64		96	66	3 1	
	Hester I	R			"		"		11.2			3		24		14	1 (14) 1	50%
		NR	"	"		"		"	2.1	8	24		3		16	13	2 2	
	Hester II	R			"		"		11.2			16		48		32	1 (27) 1	30%
		NR	"	"		"		"	2.1	16	20		32		20	22	3 1	

* Yield difference for significance: 4.5 bus. at 5% level.

Table 112 - Predictability of crop response or non-response based on rapid soil tests for K_2O and P_2O_5 using five extracting procedures. The response in the second and fourth quadrants were predictable. The circled figure at intersection of quadrant axes is the average critical response level of the nutrient in pounds per acre. A total of 82 responses were considered for each nutrient and each extracting solution.

Crop and Soils Group	Nutrient	Response Group	Number of locations where soil test values were less than, or more than, the average critical response level -														
			Bray			Morgan			Hester I			Hester II			Thornton		
			Less	Crit.	More	Less	Crit.	More	Less	Crit.	More	Less	Crit.	More	Less	Crit.	More
Corn - Coastal Plains Soils	K_2O	Responding Soils	9	106	-	5	93	4	5	62	4	5	48	4			
		Nonresponding Soils	7		8	7		8	11		4	7		8			
	P_2O_5	Responding Soils				8	16	3	5	13	6	7	26	4	7	74	4
		Nonresponding Soils				3		10	7		6	9		4	9		4
Corn - Limestone Valley ~~Soils~~	K_2O	Responding Soils	3	223	10	5	153	8	5	109	8	5	103	8			
		Nonresponding Soils	2		5	7		-	7		-	3		4			
	P_2O_5	Responding Soils				5	7	7	8	28	4	8	13	4	8	8	4
		Nonresponding Soils				6		2	4		4	7		1	7		1
Peanuts - Coastal Plains	K_2O	Responding Soils	4	118	3	5	94	2	5	98	2	5	93	2			
		Nonresponding Soils	8		5	11		2	7		6	7		6			
	P_2O_5	Responding Soils				7	22	5	7	34	5	6	29	6	7	60	5
		Nonresponding Soils				5		3	5		3	5		3	5		3
Wheat - Mountain Soils	K_2O	Responding Soils	5	167	3	3	137	5	6	114	2	6	76	2			
		Nonresponding Soils	3		7	3		7	6		4	6		4			
	P_2O_5	Responding Soils				7	15	2	5	23	4	9	17	-	7	15	2
		Nonresponding Soils				4		5	3		6	6		3	4		5
% Predictable response - K_2O			56%			43%			43%			52%					
% Predictable response - P_2O_5						57%			54%			50%			51%		

D. BALANCE SHEET INTERPRETATION

1. Development:

The balance sheet interpretation of rapid soil tests is being used very successfully at the present time with truck crops on Coastal Plains soil types (28). Figures I to V, pp. 232 to 236, illustrate graphically the manner in which the interpretation is made.

In Table 113, p. 231, are listed the calculated nutrient equivalents of crop yields for various crops. These figures were applied to the data for three calibration experiments on corn in the Coastal Plains area in order to develop the graphs in Figures I to III. The nutrient equivalent for each plot is represented by an arrow surmounted by a bar. The bar represents the quantity of the nutrient which was furnished in the form of commercial fertilizer. The arrow represents the balance of that which was required to make the crop, and which presumably came from the soil.

In preparing these charts, the nitrogen and potash in the fertilizer were considered to be 100% available. Actually, 10 to 20% leeway must be allowed for variability in seasons, - according to the interpretation as applied by Hester (28). For phosphate Hester postulates 10 to 20% efficiency. In the charts, the bar for fertilizer phosphorus represents 20% of that which was applied.

The dotted lines running horizontally across the charts represent soil nutrient supplies as revealed by the indicated rapid soil test solutions.

In Figure I the test for P_2O_5 with Hester II was 16 pounds per acre. According to Table 113, this would be equivalent to 30 bushels of corn. Actually the yield on the check plot was 30 bushels and that on the 2-0-6 plot was 33.7 bushels. Addition of 18 pounds of P_2O_5 (or 3.6 pounds effectively available) to the 16 pounds in the soil would make possible 35 bushels of corn, - the yield for 300 pounds of 2-6-6 was 38.2. For 300 pounds of 2-12-6 (7.2 pounds effectively available P_2O_5), the expected yield would be 40 bushels, - actually it was 37.6.

Thus, the interpretation for phosphorus would appear to be fairly workable to this point. However, the next two increments failed to give anything even closely approximating the increases which would have been expected. Some other factor imposed a ceiling on yields at about 38 bushels per acre. Leaf symptoms and plant tissue tests indicate that this limiting factor was nitrogen.

In the system used by Hester, organic matter is also determined on soil samples by a wet oxidation procedure (28). In making fertilizer recommendations for tomatoes, organic matter is converted to available soil nitrogen by calculating it at 5% total nitrogen, of which 5% is nitrified annually in sandy soils (less in heavy soils).

If, in Figure I, it is estimated that this Onslow fine sandy loam contained 1 1/2% organic matter, then the above calculation would have indicated 75 pounds of available nitrogen in the soil. Obviously this was not the case, - unless the low tests for MgO should be interpreted as meaning that magnesium was the first limiting factor. Magnesium very probably was present in inadequate supply, but leaf symptoms and plant tissue tests still point to nitrogen as the first limiting factor. If the fertilizer nitrogen is considered to be 100% effective, then the indicated level of available soil nitrogen in Figure I would have been 20 to 25 pounds, or the equivalent of 1% organic matter in the soil. This seems low for Onslow. More probably, a different nitrification factor is called for with corn than with tomatoes. Also, fertilizer nitrogen very probably is not 100% efficient.

At any rate, the above indicates the importance of the organic matter determination to the balance sheet interpretation and the importance of calibrating it for specific crops in terms of available soil nitrogen.

In Figure I the test for K_2O by Hester I and II very closely approximates the limiting level indicated by the K_2O equivalent of the yield on the 2-12-0 plot. The response to the first 18-pound increment of K_2O shows considerably less than 100% efficiency in the utilization of the potash. Additional increments are even less efficient. Limiting nitrogen and magnesium are responsible for this to a great extent on these particular plots. However, a comparison of fertilizer applications with the nutrient equivalents of crop yield increases for the data in Tables 28 through 63 revealed only a few instances where greater than 75% efficiency was achieved in the utilization of applied potash by corn, cotton or peanuts.

In Figure II, p.233 , the level of soil P_2O_5 indicated by Hester I could be interpreted as limiting crop yields in the variable potash series of plots. The response to phosphate at all rates of application in the variable P_2O_5 series also follows this level quite closely, as is indicated by the arrows which represent P_2O_5 supplied by the soil.

On the other hand, the 48 pound level shown by Hester II for P_2O_5 bears no relation to the yield levels actually achieved, - although in Figure I it was Hester II which gave the value most closely related to actual yields. This variability in significance of soil test values by individual extractants makes exact interpretation on a balance sheet basis impossible. For this reason, in the system used by Hester, only three interpretative levels of each nutrient are recognized, - "good," "fair" and "poor." Thus, the system is based essentially on a high-low-medium interpbetation.

At first glance, the 60 pound level of K_2O by Hester I in Figure II would appear to tie in quite well with the limiting level suggested by the yield on the 2-12-0 plot. On the other hand, the soil-provided portion of the K_2O equivalents of the yields on the variable phosphate series of plots might be interpreted to mean that K_2O was limiting at the 45 pound level shown by Hester II. However, plant tissue tests indicate that nitrogen was limiting. Also, magnesium tests were low with all extractants (although higher than in Figure I). A more adequate magnesium supply and a higher rate of nitrogen fertilization could conceivably have raised yield levels to the point where no correlation could be made with the test by either extractant.

Except for one discordant yield on the 2-12-0 plot, the data represented graphically in Figure III, p. 234 might be interpreted very nicely on the basis of the limiting levels of K_2O and P_2O_5 revealed by Hester II. However, soil tests and deficiency symptoms both point to magnesium as the first limiting factor. Plant tissue tests for nitrogen were very low on several plots. If these deficiencies had been corrected, the tests for K_2O and P_2O_5 with this extractant would very probably have lost all significance.

Thus, the balance sheet interpretation of rapid soil tests for the major nutrients is predicated upon the prior elimination of all other limiting factors. Further, the interpretation cannot be made at all on only partial data. The absence of any reliable test for estimating seasonally available soil nitrogen in connection with the calibration trials reported here makes them valueless for a balance sheet correlation.

Graphs similar to Figure I to II were prepared for the remainder of the calibration trials for corn on Coastal Plains soils, as well as for those on cotton and peanuts. A study of these graphs showed that in every case the tests for potassium with Bray's solution were higher in pounds per acre than the total potash equivalent of the maximum fertilized crop yields. However, the tests with this extractant could be utilized in a balance sheet interpretation for cotton and corn on Coastal Plains soils by assuming that 1/3 to 1/2 of the potash revealed by the test was available to the crop. A somewhat higher percentage of the potash tests with Morgan's solution might be considered available, while 75 to 100% of the potash tests with Hester I and II could be considered available to these two crops. The utilization of indicated soil potassium by peanuts was much lower, equal only to about 1/3 to

1/2 of the soil supplies indicated by Hester I and II.

In the case of phosphate, the tests with Hester I and II and Morgan's solution could be interpreted on the basis of 75 to 100% availability of soil P_2O_5 for all three crops on Coastal Plains soils.

It must be remembered that these availabilities of soil-test P_2O_5 and K_2O for corn are based upon plant stands and rates of nitrogen fertilization considerably lower than those in vogue at the present time (34). Leaf deficiency symptoms and low plant tissue tests for nitrogen at most locations indicate that yield levels were limited by an inadequate supply of this nutrient. The significance of soil tests for P_2O_5 and K_2O in a balance sheet interpretation will need to be reassessed in terms of new developments in corn culture.

Tissue tests (Table 41) suggest that limiting nitrogen may have been a factor in the calibration trials on cotton, also.

The low utilization by peanuts of indicated soil supplies of K_2O (and of P_2O_5, at two locations) suggests some other limiting factor (compare nutrient utilization in Figure IV with the corresponding soil tests for P_2O_5 and K_2O in Table 52, p. 101). In several cases this limiting factor could have been magnesium, although magnesium was applied with the fertilizer at the rate of 80 pounds of dolomitic limestone per acre. The pattern of response to increasing rates of P_2O_5 and K_2O was similar at all locations, regardless of the indicated level of MgO in the soil (Tables 44 to 53). The August tissue tests at most locations were low to medium, indicating good utilization of both phosphate and potash within the plant, - even at the highest rates of application. This would suggest that the limiting factor was not nutritional. If not nutritional, then the further possibility suggests itself that a stand factor is involved in the response of peanuts, to fertilization, as has been demonstrated more recently in the case of corn (34).

Graphs were prepared representing the nutrient equivalents of the yields on the five experiments with corn on Limestone Valley soils for which data is tabulated in Tables 54 to 63. Moisture was limiting at most of these locations. However, at several locations a satisfactory balance sheet correlation could be made with the test values for P_2O_5 with Hester I and II and Morgan's solution when 10% efficiency was assumed for the phosphate in the fertilizer (Figure V). These correlations were achieved at yield levels of from 20 to 50 bushels per acre. It is highly questionable if these same test values would have had any significance at yield levels of 60 to 80, and even more, bushels per acre, which are currently being obtained with high rates of nitrogen fertilization.

On the other hand, potash tests with all extractants were several times greater than the maximum quantity indicated as having been utilized from the soil by the crop. If a 40 bushel crop of corn requires only 44 pounds of K_2O for its manufacture, then a 280 pound test (with Bray's solution), which must be interpreted as limiting, loses all meaning as far as a balance sheet interpretation is concerned. The discrepancy between indicated crop utilization and the tests for potash with Hester I and II were not so extreme, but it did not appear that the relationship was consistent enough for a simple correction factor or percentage availability to be applied.

When these extreme discrepancies between tests for K_2O and the response of corn became apparent during the first attempts to analyze the data in the winter of 1946, organic matter determinations were made on the soil samples which had been taken in connection with the experiment on corn for which the basic data is tabulated in Tables 6 and 7. In Table 114, p. 237, the total N, P_2O_5 and K_2O utilized in producing the yields on these plots are compared with the total estimated to have been made available to the crop in the soil and the fertilizer. Soil nitrogen was calculated as 5% of the organic matter with 2.5% nitrified annually. Fertilizer nitrogen was considered to be 100% available, P_2O_5 was considered 10% available, and K_2O, 75% available to the crop.

The totals for nitrogen available and nitrogen in the crop are very closely equivalent. Those for P_2O_5 and K_2O differ widely. Thus, it would appear that the supply of nitrogen established the yields on these plots, so that no correlations for P_2O_5 or K_2O were possible.

In Table 115, p. 238, are cited similar figures for wheat on Berks silt loam at Staunton. Here the close equivalence between total P_2O_5 available and the P_2O_5 in the crop suggests that the level of wheat yields was determined by the available supply of phosphate. The major increases in yields of wheat were also in response to phosphate, which would further indicate that nitrogen and potash were present in adequate quantities. The small increases for fertilizer nitrogen and potash appear to have been due to the boost given to the seedlings at early stages of growth. Thus, the nitrogen and potash applied in the fertilizer served in the role of starter fertilizers, whereas the applied phosphate was the major source of supply of that nutrient.

It is known that wheat responds very well to early spring top-dressings of manure or commercial nitrogen. In interpreting organic matter determinations in terms of nitrogen available to wheat, it must be considered that wheat makes much of its vegetative growth during a period of the year when the availability of soil nitrogen is low. Corn makes most of its growth during the period of maximum availability of soil nitrogen. This contrast between corn and wheat illustrates the necessity for calibrating soil tests for organic matter in terms of the agronomic behavior and seasonal nitrogen requirements of individual crops.

The very different behavior of corn and wheat with respect to indicated soil supplies of P_2O_5, which is indicated by a comparison of Tables 114 and 115, emphasizes the difficulties in the way of developing a balance sheet interpretation for crops that differ greatly in feeding power and plant food needs. It seems quite likely that more than one extracting solution would need to be used to meet the balance sheet correlation requirements of the wide variety of crops grown in any one of the soil provinces in Virginia.

In Table 115, the effect of lime in making soil P_2O_5 more available, and in increasing the efficiency of applied P_2O_5, again illustrates the observation already made that a successful balance sheet interpretation for the major nutrients involves the prior elimination of all other limiting factors.

This qualifying consideration was established as a general principle in the interpretation of soil tests by Spurway, quote: "Results from microchemical soil tests cannot be correlated directly with crop response to fertilizers except over the range in which the element in question is limiting. If some other element or factor is the limiting one, then the test cannot be used as an indicator of crop response. On the other hand, if a high phosphorus test is obtained, some other factor may be limiting, and if this other factor be corrected, the soil may respond to further additions of phosphorus." (45).

This principle has been seen in operation all through the data which was used for the high-low-medium and balance sheet interpretations in this study. Nitrogen or magnesium were limiting in the corn and cotton trials on Coastal Plains soils. Some non-nutritional factor, possibly stand density, appeared to limit peanut yields. Moisture was limiting with corn on the Limestone Valley soils. In only a few instances was it possible to definitely demonstrate a deficiency of phosphate or potash.

The unsatisfactory correlations for phosphate and potash are due, at least in part, to a faulty plan of procedure in the calibration trials. In the case of each crop in each area, a uniform schedule of treatments was used, without regard to variations in pH, organic matter or nutrient balance between locations. Soil samples were taken at the time of applying the fertilizers but were not analyzed until later. At that time the information revealed by the soil tests was of value only as it provided clues for explaining the lack of any correlations between the tests for P_2O_5 and K_2O and crop response to them.

Had the soil tests been made first and used as the basis for setting up the schedule of calibration treatments, other limiting factors could have been eliminated. Critical response levels for phosphate, or potash, or at some locations for both nutrients, could have been established more definitely. The data that was obtained, in most cases, gave a sounder basis for correlation with the magnesium test or with an organic matter test than with the tests for the two nutrients of primary concern in the study as it was originally outlined.

The data cited in Table 115 does quite definitely establish phosphate as limiting. However, soil tests for P_2O_5 range from 3 to 16 pounds per acre. All must be interpreted as deficient for wheat. Obviously it is impossible to interpret these soil tests exactly in terms of P_2O_5 available to the crop for purposes of a balance sheet interpretation. Rather, they must all be lumped into one interpretative category. The system employed by Hester recognizes three such categories, - "good", "fair" and "poor." It would appear, therefore, that even after a calibration has been worked out, the balance sheet concept offers no possibilities for any more accurate definition of soil test values than does the high-low-medium interpretation.

There is one other factor which raises a question as to the validity of the basis upon which correlations were established for phosphate and potash in this study, - both in the section on the high-low-medium interpretation and in the interpretation based upon a balance sheet. That is the "starter fertilizer" effect noted in the experiments with peanuts and in the data for wheat in Table 115. The data indicates that it is possible to get responses to initial increments of a fertilizer nutrient even where adequate supplies for maximum crop yields are present in the soil. It seems reasonable to question the soundness of using crop response to initial increments as a criterion for establishing response categories for a nutrient in the high-low-medium interpretation. It is difficult to reconcile such responses with a strict balance sheet correlation. This "starter fertilizer" effect should be considered in future calibration studies.

2. Conclusions:

In summarizing the balance sheet interpretation as applied to the data cited here, several conclusions may be drawn:

1. Soil tests for K_2O with Hester I and II on Coastal Plains soils appear to be suitable for this interpretation for corn and cotton.

2. Soil tests for P_2O_5 with Hester I and II and Morgan's solution also appear suitable for use with corn and cotton on Coastal Plains soils in a balance sheet system of interpretation. There were a few discrepancies in the correlation with peanuts, but, in general the correlations were workable.

3. None of the extractants gave test values for K_2O which could be correlated with the response of peanuts to potash fertilization. Some non-nutritional limiting factor was indicated.

4. Tests for P_2O_5 with Hester I and II and Morgan's solution

Table 113 - Calculated nutrient equivalents of crop yields for various crops.

Crop	Yield per acre	Nutrients required to produce crop - Pounds per acre				
		N	P_2O_5	K_2O	CaO	MgO
Corn	1 bus.	1.6	0.6	1.1	0.4	0.2
	5 "	7.8	2.8	5.5	2.0	0.9
	20 "	31.2	11.2	22.0	8.0	3.6
	30 "	46.8	16.8	33.0	12.0	5.4
	40 "	62.4	22.4	44.0	16.0	7.2
	↓50 "	78.0↓	28.0↓	55.0↓	20.0↓	9.0↓
	60 "	93.6	33.0	66.0	24.0	10.8
Cotton	(seed & lint)					
	100 lbs.	4.33	1.67	3.33		
	500 "	21.7	8.4	16.7		
	1000 "	43.3	16.7	33.3		
	*1500 "	65.0*	25.0*	50.0*		
	2000 "	86.6	33.4	66.6		
Peanuts	100 lbs.	4.25	0.75	2.5		
	500 "	21.3	3.8	12.5		
	1000 "	42.5	7.5	25.0		
	1500 "	63.8	11.3	37.5		
	*2000 "	85.0*	15.0*	50.0*		
Wheat	1 bus.	1.67	0.67	1.0		
	5 "	8.4	3.4	5.0		
	10 "	16.7	6.7	10.0		
	20 "	33.4	13.4	20.0		
	*30 "	50.0*	20.0*	30.0*		
	40 "	66.7	26.7	40.0		

↓ From a table compiled by the editors of THE FARM QUARTERLY, Winter Issue, 1946, p. 28.

* From a table compiled by J. D. Romaine in BETTER CROPS WITH PLANT FOOD MAGAZINE (reprint F-3-40).

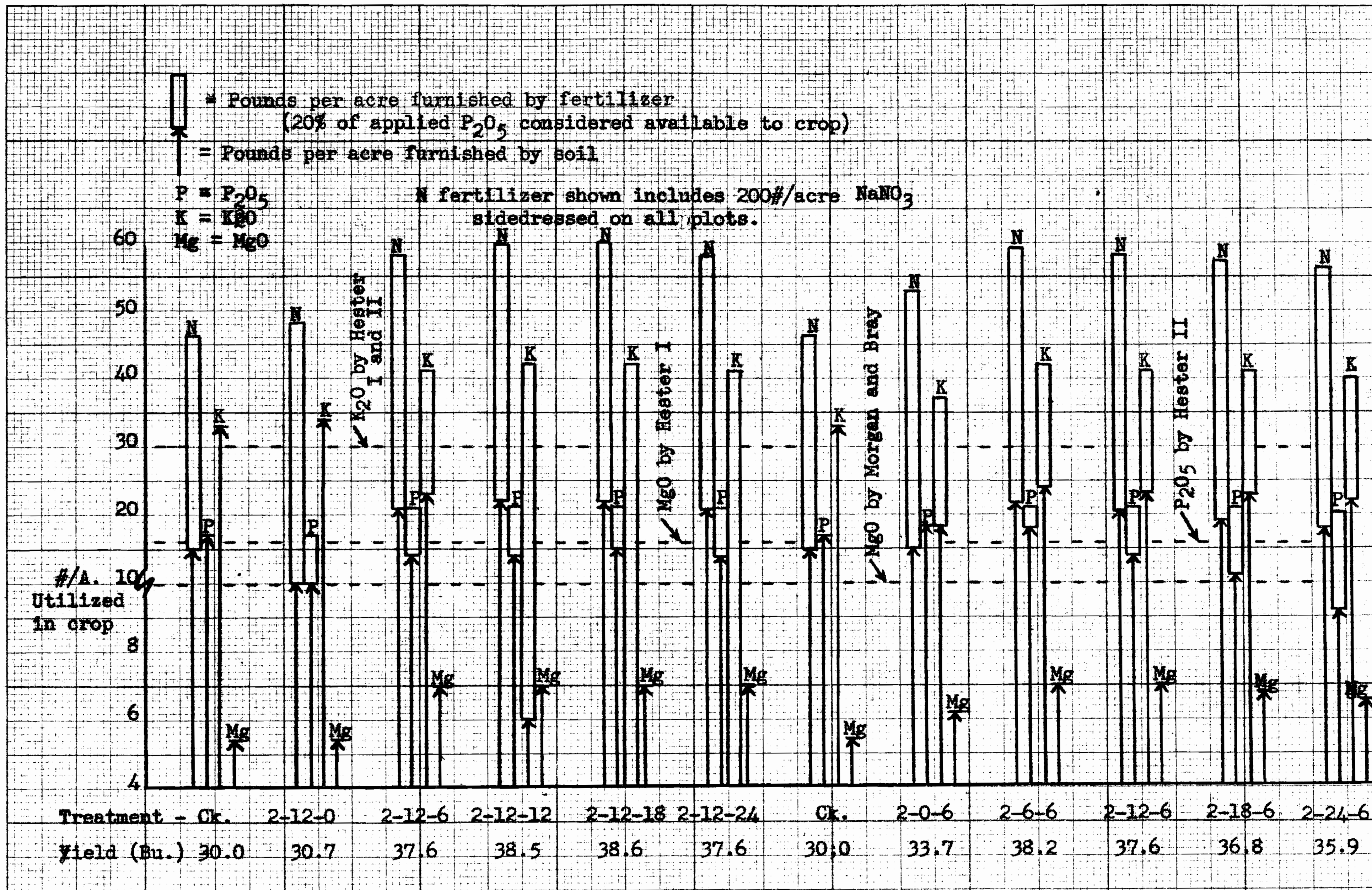

FIG. I - CORN ON ONSLOW FINE SANDY LOAM - GRAPHICAL PRESENTATION OF DATA IN TABLES 28 AND 29 TO ILLUSTRATE BALANCE SHEET INTERPRETATION OF RAPID SOIL TESTS.

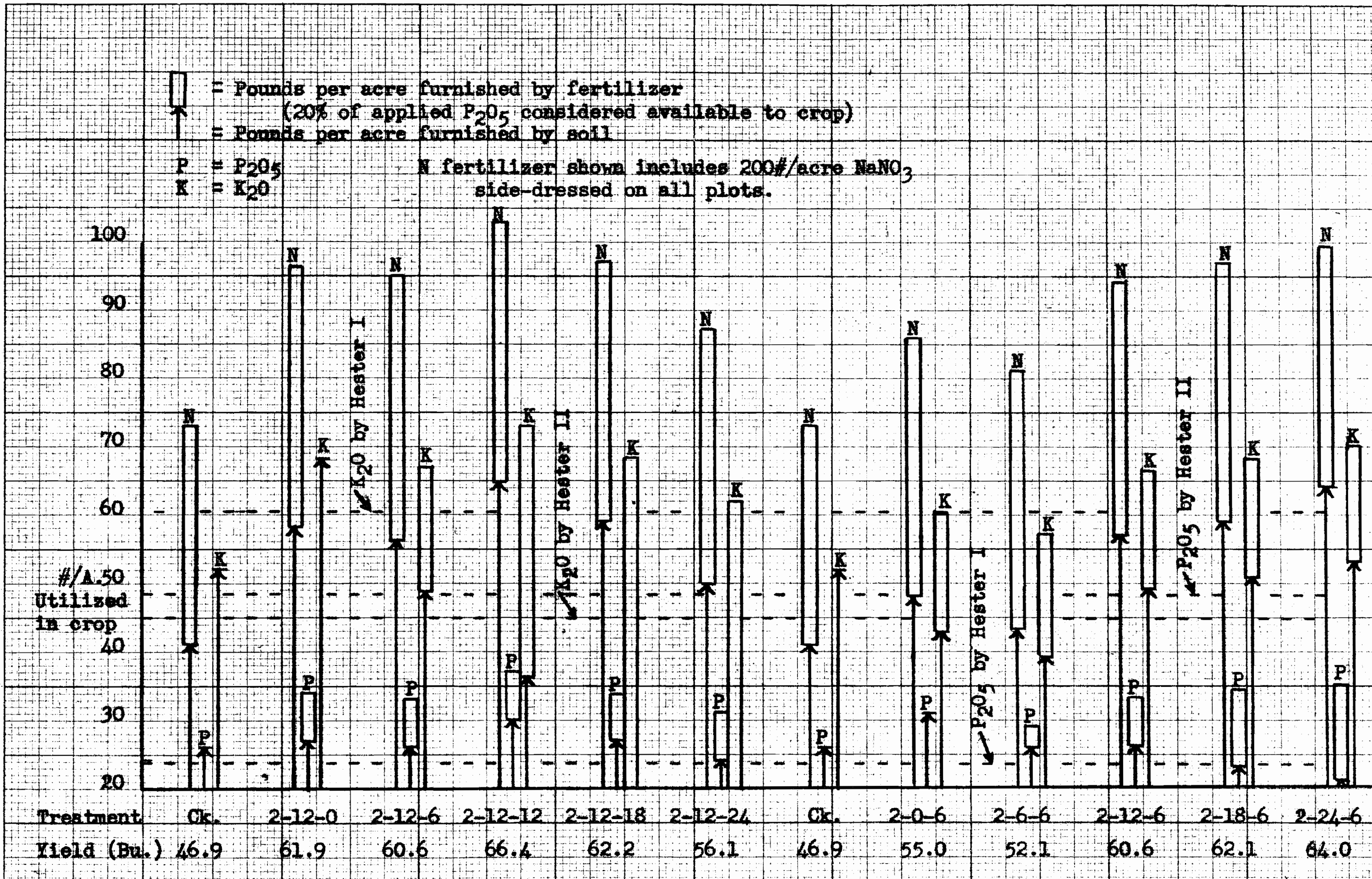

FIGURE II - - CORN ON NORFOLK FINE SANDY LOAM - GRAPHICAL PRESENTATION OF DATA IN TABLES 36 AND 37 TO ILLUSTRATE BALANCE SHEET INTERPRETATION OF RAPID SOIL TESTS.

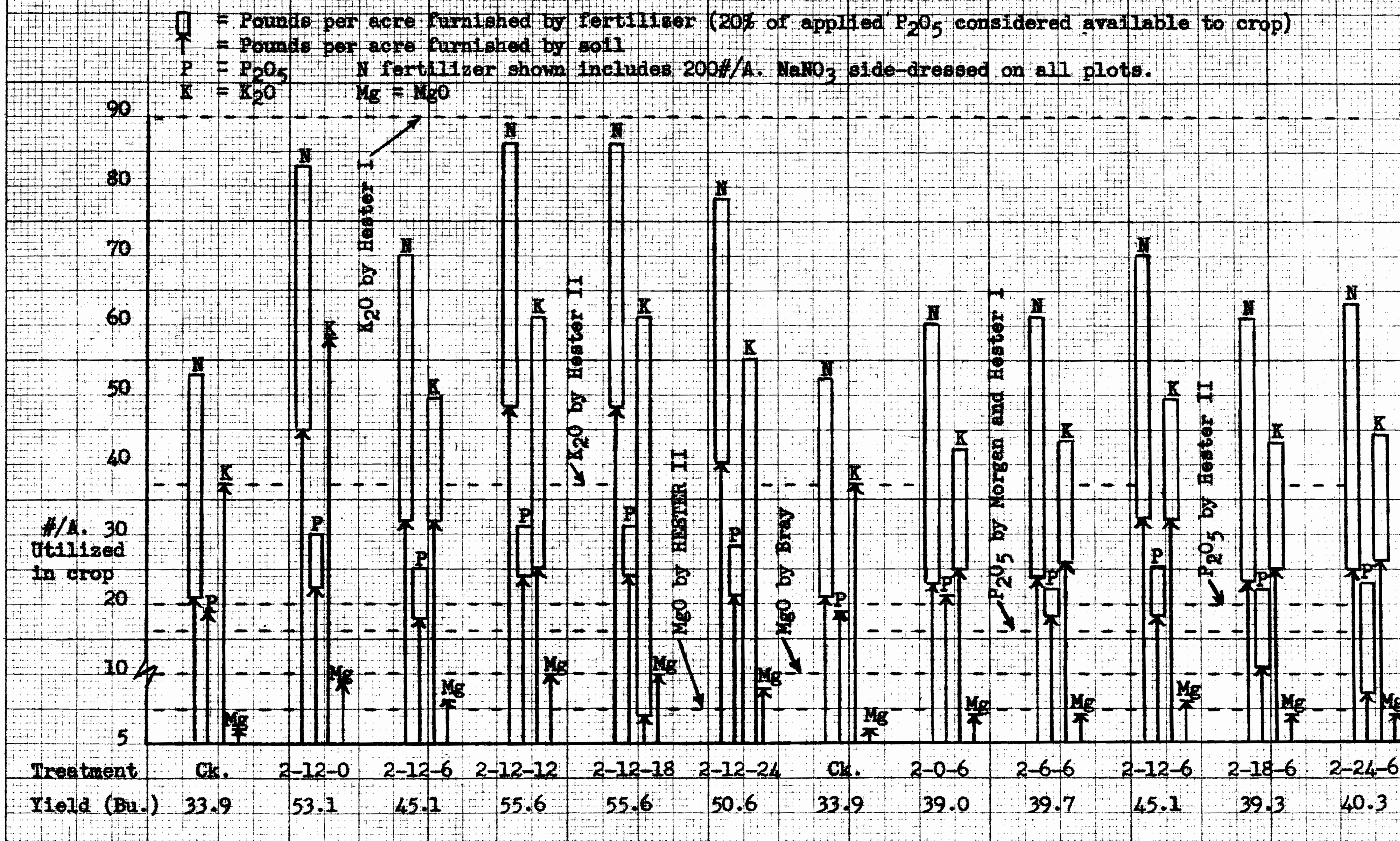

FIGURE III - - CORN ON NORFOLK SANDY LOAM - GRAPHICAL PRESENTATION OF DATA IN TABLES 38 AND 39 TO ILLUSTRATE BALANCE SHEET INTERPRETATION OF RAPID SOIL TESTS.

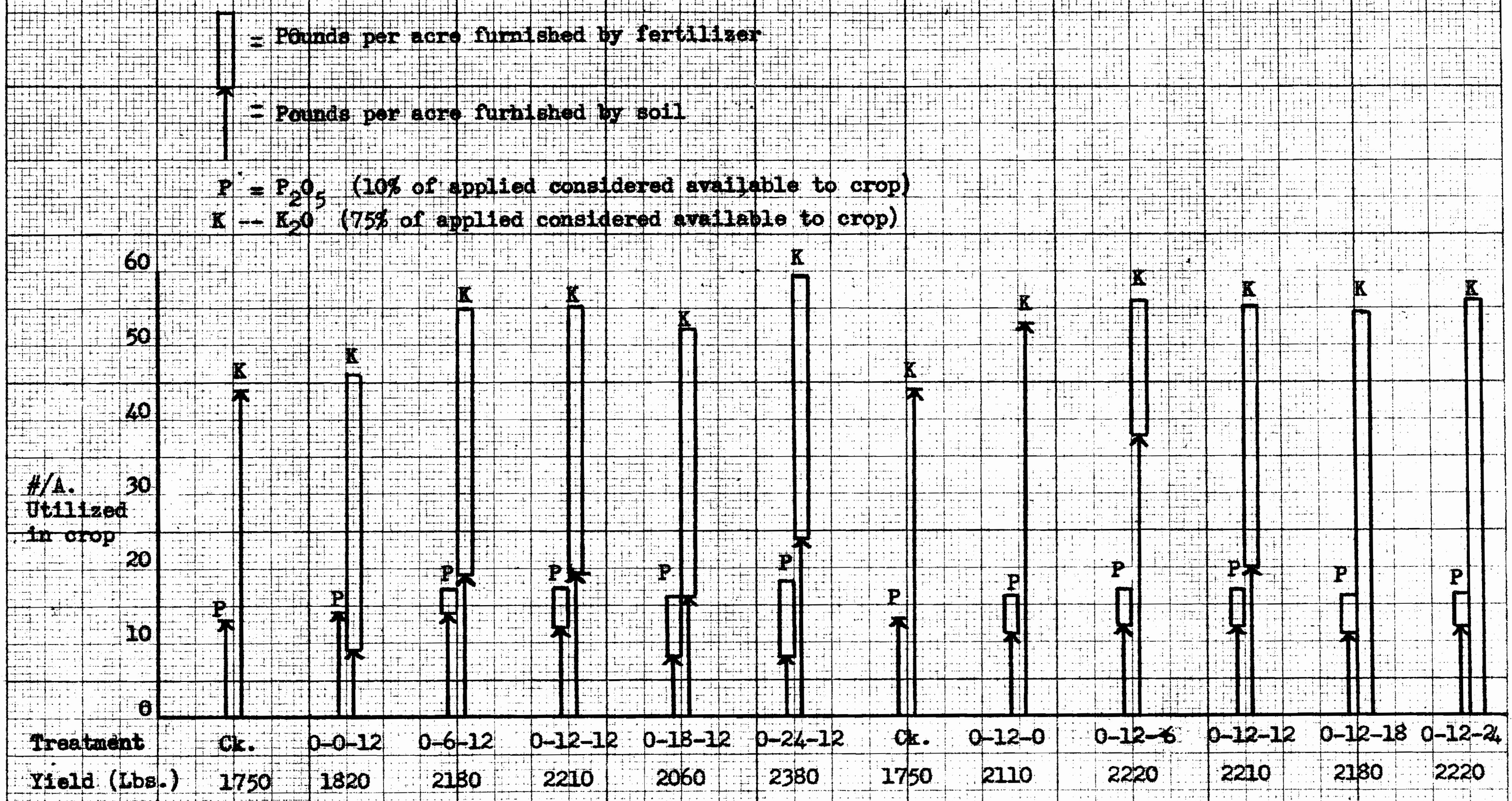

FIGURE IV - - PEANUTS ON NORFOLK SANDY LOAM - GRAPHICAL PRESENTATION OF DATA IN TABLES 52 AND 53 TO ILLUSTRATE THE FAILURE OF THE BALANCE SHEET INTERPRETATION OF RAPID SOIL TESTS WHEN APPLIED TO PEANUTS. (COMPARE THE NUTRIENT UTILIZATION INDICATED HERE WITH THE SOIL TESTS FOR P_2O_5 AND K_2O IN TABLE 52, P. 101).

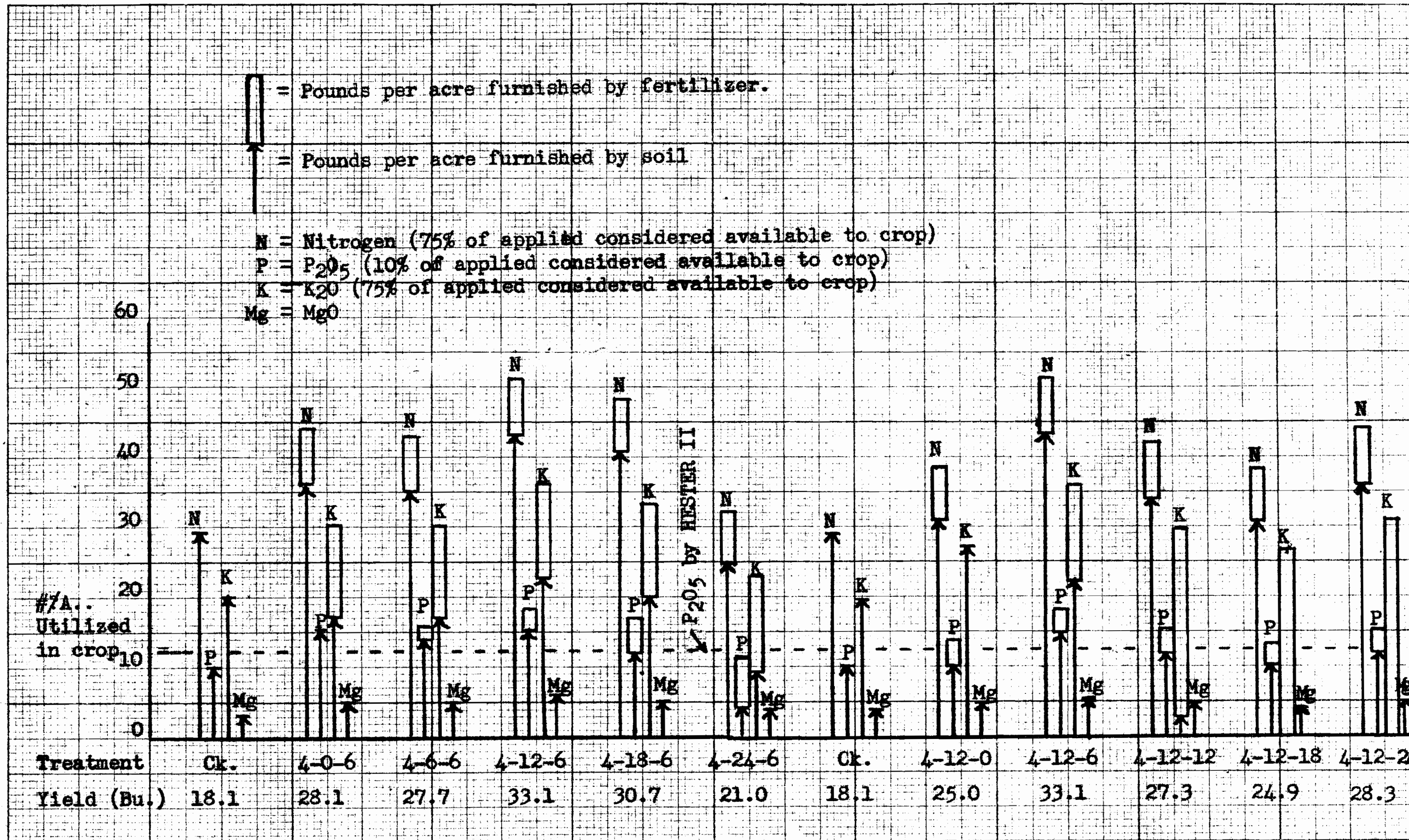

FIG. V --- CORN ON FREDERICK SILT LOAM - GRAPHICAL PRESENTATION OF DATA IN TABLES 54 AND 55 TO ILLUSTRATE BALANCE SHEET INTERPRETATION OF RAPID SOIL TESTS. (GOOD CORRELATION WITH P_2O_5 BY HESTER II, NONE WITH TESTS FOR K_2O.. SEE TABLE 54, P. 103)

Table 114 - Nutrient balance sheet for corn on Dunmore silt loam. Blacksburg data from basic data Tables 6 and 7.

Plot	Treatment	Yield Bus.	N - #/A. *Available Soil	Fertilizer	Total	In Crop	P_2O_5 - #/A. * Available Soil	Fertilizer	Total	In Crop	K_2O - #/A. *Available Soil	Fertilizer	Total	In Crop
1	Check	61.8	60	—	60	97	8	—	8	35	150	—	150	68
2	500# 12-0-12	83.2	50	60	110	130	8	—	8	47	120	45	165	92
3	500# 12-6-12	65.4	56	60	116	102	16	3	19	37	210	45	255	72
4	500# 12-12-12	71.3	58	60	118	111	16	6	22	40	120	45	165	79
5	500# 12-24-12	68.9	52	60	112	107	64	12	76	39	120	45	165	76
6	500# 12-12-0	68.9	48	60	108	107	16	6	22	39	90	—	90	76
7	500# 12-12-20	77.3	59	60	119	121	24	6	30	43	210	75	285	85
8	500# 12-12-40	68.3	53	60	113	106	24	6	30	38	300	150	450	75

* Note: Available soil supplies of N were based on the organic matter content of the soil. Organic matter was considered to carry 5% N, of which 2.5% is nitrified annually.

Soil test values with Hester II extractant were listed as available soil supplies of P_2O_5 and K_2O.

Availability of fertilizer nutrients was considered to be as follows:

N — 100%

P_2O_5 — 10%

K_2O — 75%

Table 115 - Nutrient balance sheet for wheat on Berks silt loam. Staunton data from basic data Table 18.

Plot	Treatment	Yield Bus.	N				P_2O_5				K_2O			
			* Available				* Available				* Available			
			Soil	Fertilizer	Total	In Crop	Soil	Fertilizer	Total	In Crop	Soil	Fertilizer	Total	In Crop
	Without Lime													
1	Check	3.6	46	--	46	6.0	3.2	---	3.2	2.2	30	--	30	3.6
2	400# 0-8-0	7.6	53	--	53	12.7	16.0	3.2	19.2	4.6	30	--	30	7.6
3	400# 0-8-5	9.2	48	--	48	15.4	3.2	3.2	6.4	5.5	30	15	45	9.2
4	400# 5-8-5	9.8	50	20	70	16.4	3.2	3.2	6.4	5.9	30	15	45	9.8
5	400# 5-16-5	12.6	51	20	71	21.0	8.0	6.4	14.4	7.6	30	15	45	12.6
6	400# 5-8-15	11.3	50	20	70	18.9	3.2	3.2	6.4	6.8	30	45	75	11.3
7	400# 5-16-10	13.1	52	20	72	21.9	8.0	6.4	14.4	7.9	30	30	60	13.1
	With lime													
8	Check	5.1	42	--	42	8.5	3.2	---	3.2	3.1	30	--	30	5.1
9	400# 0-8-0	13.8	54	--	54	23.0	8.0	3.2	11.2	8.3	30	--	30	13.8
10	400# 0-8-5	17.3	47	--	47	28.9	8.0	3.2	11.2	10.4	30	15	45	17.3
11	400# 5-8-5	18.6	45	20	45	31.1	8.0	3.2	11.2	11.2	30	15	45	18.6
12	400# 5-16-5	20.0	47	20	47	33.4	3.2	6.4	9.6	12.0	30	15	45	20.0
13	400# 5-8-15	19.3	53	20	53	32.1	8.0	3.2	11.2	11.6	30	45	75	19.3
14	400# 5-16-10	21.1	50	20	50	35.2	3.2	6.4	9.6	12.7	30	30	60	21.1

* Note: Available soil supplies of N were based on the organic matter content of the soil. Organic matter was considered to carry 5% N, of which 2.5% is nitrified annually.

Soil test values with Hester I extractant were listed as available soil supplies of P_2O_5 and K_2O.

Availability of fertilizer nutrients was considered to be as follows:

N -- 100%
P_2O_5 -- 10%
K_2O -- 75%

appeared to fall in a significant range for a balance sheet interpretation for corn on the Limestone Valley soils.

5. All of the extracting solutions gave tests for K_2O on Limestone Valley soils which were too high for interpretation on a balance sheet basis for corn, - even at much higher yield levels. The relationship between tests for K_2O and actual nutrient utilization by the crop was too erratic to allow a simple correction factor to be used.

6. The successful calibration of a balance sheet correlation for any major nutrient, - and its subsequent interpretation, - are possible only after the prior elimination of all other limiting factors.

7. To fulfill the requirement of the preceding paragraph, locations for calibration studies will need to be selected more carefully than was the case in this study. A preliminary survey of possible locations is suggested. This survey should include the taking of soil samples and preliminary testing of them to reveal potential deficiencies. On the basis of this information a separate schedule of treatments should be set up for each location such as to definitely establish critical response levels for the one or more nutrients in question.

8. A reliable test for estimating seasonally available soil nitrogen is essential to the calibration and its interpretation.

9. At best, only an approximate balance sheet correlation can be made. Three interpretative ranges of soil test values appears to be the maximum definition possible. Thus, the balance sheet must be based, essentially, upon two critical response levels, - as was the case with the high-low-medium interpretation.

10. It appears that a separate balance sheet calibration would have to be made for each of the major crops on each of the major soil groups in Virginia, - particularly for crops which differ greatly in physiology and seasonal plant food requirements.

11. A different extracting solution for potash would have to be used on Limestone Valley soils than on Coastal Plains soils.

12. At least three years would be required to develop a reliable balance sheet calibration for a given crop in each soil area. The useful life of such a calibration would probably end with the general adoption in an area of new developments in cultural practice which materially altered the productive efficiency of the crop. (The recent revolutionary changes in corn culture in the Southeast are examples). A new calibration would then be necessary.

E. GROWTH CURVE INTERPRETATION

1. Concept and formulas:

The growth curve interpretation as developed by Bray (11, 13) is based upon a modification of an equation proposed by Mitscherlich as "the law of the soil," or "the law of action of the growth factors." The Mitscherlich equation is based on the assumption that "the yield increases in proportion to the amount by which the current yield fails of the maximum yield, A." It is expressed as follows:

$$\frac{dy}{dx} = (A-y)c \qquad \text{(Equation \#1)}$$

By integration this gives Mitscherlich's working equation:

$$\text{Log } (A-y) = \log A - c\,(x + b) \qquad \text{(Equation \#2)}$$

where A = maximum yield
y = yield when x units of nutrient are added to a certain amount of soil.
b = original nutrient content of soil expressed in same units as x.
c = proportionality constant or working factor.
x = units of nutrient applied in fertilizer to a certain amount of soil.

Bray's modification of Mitscherlich's working equation is stated as follows:

$$\text{Log } (A-y) = \log A - c_1 b_1 \qquad \text{(Equation \#3)}$$

where A = yield when nutrient is not deficient
y = yield when none of the nutrient is added
b_1 = pounds per acre of the nutrient available in the surface soil as measured by test.
c_1 = proportionality constant for nutrient in the soil.

A further modification of Equation #3 takes into account crop response to applications of the nutrient:

$$\text{Log } (A-y) = \log A - (c_1 b_1 + cx) \qquad \text{(Equation \#4)}$$

where A = 100% (yield when nutrient is not deficient)
y = yield for known application (x) of the nutrient, expressed as a percent of Yield A
b_1 = soil test value for the nutrient
c_1 = proportionality constant for b_1
x = known fertilizer application of the nutrient expressed in same units as b_1
c = proportionality constant for x

In the application of the interpretation it is necessary to employ a concept which Bray refers to as the "fertility rating" or "percentage yield" of a given field or limited soil area. This is perhaps better referred to as the "percentage sufficiency" of the nutrient, and it is based solely upon the soil test for the nutrient for a given field and the established c_1 value for the soil group to which the field soil belongs. The "percentage yield" is determined by substitution in Equation #3, as follows:

$$\text{Log } (100-y) = \log 100 - c_1 b_1 \qquad \text{(Equation \#5)}$$

where y = "percentage yield" on soil of b_1 soil test without fertilizer additions of the nutrient
100 = 100% (the yield when the nutrient is not deficient)

The yield "A" in Equation #3, or the 100% yield in Equation #5, do not represent a theoretical maximum yield where none of the nutrients are deficient. Rather, they represent the yield obtained in any case where the one nutrient under consideration is adequate for the given situation. In other words, in considering the data for any particular ratio experiment at a given location, yield "A" is the yield beyond which there are no further increases for added increments of the nutrient, when the nutrient is the only variable.

The proportionality constant "c_1" characterizes the response of a given crop to varying levels of the nutrient in the soil as revealed by the soil test. It is essentially a constant for a given crop on any group of similar soils varying widely in productivity. It is independent of other limiting factors within the range where these other factors are not acutely limiting. Other limiting factors will normally establish the maximum yield "A" at any given location. They will not affect c_1 for the nutrient under consideration within the range that yields are influenced by the b_1 (soil test) values for that nutrient. The c_1 value will be different for different crops.

The accurate calculation of c_1 for a given nutrient, using Equation #3, involves the following assumptions:

a. Yield A is the maximum yield for the nutrient at each of the calibration locations on a given group of similar soils and similar situations.

b. The difference between yields A and y at each location is due entirely to the nutrient in question.

c. The value for b_1 shown by the soil test is a measure of the amount of the nutrient actually available to the crop.

According to Bray (13) the premise in assumption c above will be met for K_2O only if the test reveals total exchangeable K_2O. For P_2O_5 the test must include both replaceable and acid soluble P_2O_5.

In Equation #4, the proportionality constant "c" must be determined for each form of the nutrient commonly used in fertilizers. In other words the value of c will be different for 20% superphosphate than for rock phosphate, etc.

As outlined by Bray (13) the steps to be gone through in using the modified Mitscherlich equations are:

Step 1. Accurately measure the available nutrient in the soil by chemical soil test. This is b_1 in the equations. (Accurate determination of b_1 involves correct sampling techniques in the field, careful and standard procedures for preparing soil samples for testing, and the use of a rapid soil testing procedure which measures forms of each nutrient which are significant to crop response).

Step 2. Calculate "c_1" for each crop and for grouped similar soils, using Equation #3. (This involves the establishment of fertilizer ratio experiments designed to accurately establish yield "A" at each of several locations on each group of similar soils. These locations should be selected so as to adequately sample a wide range of b_1 values).

Step 3. Calculate "percentage yield" or "percentage sufficiency" of the nutrient for each b_1 value. (Percentage yield is "y" in Equation #5).

Step 4. Calculate the expected yield increase with adequate K_2O or P_2O_5. Ninety-eight percent of maximum yield is considered attainable with practical fertilizer applications.

Step 5. Calculate "c" for each form of the nutrient and for each soil, using Equation #4.

Step 6. Calculate the fertilizer requirement for 98% maximum yield for each level of "b_1" (soil test value) and for each level of soil productivity, again using Equation #4.

Step 7. Calculate the cost of the required fertilizer and the value of expected yield increases.

Much of the data gathered in this study is unsuitable to a growth curve correlation because the experiments were not designed for such a correlation. The design of the fertilizer ratio experiments cited in Tables 28 through 63 (pp. 77-112) does meet the requirements for such a correlation, except with respect to the adequate statistical definition of yield differences. These are the experiments with corn, cotton and peanuts on Coastal Plains soils, and the first five experiments with corn on Limestone Valley soils.

Unfortunately, not enough locations were sampled on any one group of similar soils with any one crop. The range of soil test values covered by the experiments with a given crop on any one soil group was also inadequate. For these reasons, no reliable growth curve correlation could be worked out with the data at hand. It was felt, however, that it would be of value to the present study to go through the mechanics of the system as outlined by Bray, using the data for corn on the group of Coastal Plains soils (Tables 28 through 39) and the group of Limestone Valley soils (Tables 54 through 63). This is done, step by step, on the following pages.

To supply additional data from one more location on Coastal Plains Soils, and two more locations on Limestone Valley Soils, the experiments cited in Tables 6, 7, 10, 22 and 23 are included with the two groups of experiments referred to in the last paragraph. Suitable b_1 values are obtained by averaging the soil tests for all plots at each location.

2. <u>Development</u>:

<u>Step 1</u>. ---- Measurement of soil nutrients.

The soil test values for K_2O and P_2O_5 which are tabulated for the several extractants in Tables 28 through 39 and Tables 54 through 63 are used in the correlation for corn as it is worked out here for purposes of illustrating the mechanics of the growth curve interpretation.

<u>Step 2.</u> ---- Calculation of "c_1".

As an example, the calculation of c_1 for K_2O for the data in Tables 28 and 29 (pp. 77 and 78), using the soil test value for Hester II extractant, is as follows:

$$\text{Log } (A-y) = \log A - c_1 b_1 \qquad \text{(Equation \#3)}$$

where $A = 38.6$ bu. (maximum yield for K_2O, 2-12-18 plot)
$y = 30.7$ bu. (yield without K_2O, 2-12-0 plot)
$b_1 = 30$ lbs./acre (Soil test for K_2O, Hester II)

$$\text{Log } (38.6 - 30.7) = \log 38.6 - (c_1 \times 30)$$
$$\text{Log } 7.9 = \log 38.6 - 30c_1$$
$$30c_1 = 1.58659 - 0.89763$$
$$c_1 = \frac{0.68896}{30}$$
$$c_1 = 0.0230$$

The above example illustrates the manner in which substitution is made in Equation #3 (p. 241). In Tables 116 through 119 (pp. 263 to 266) are tabulated the c_1 values for P_2O_5 and K_2O as calculated for the locations which were selected for the present correlation with corn yields. Listed also are the values for A, y and b_1 which were used in each calculation.

The workability of Equations #3, #4 and #5 requires that c_1 be essentially a constant for a given crop on similar soils. At the bottom of Tables 116 to 119 are listed the average c_1 value and its coefficient of variability for each extractant. The variability for all extractants is too high to permit the acceptance, even tentatively, of the c_1 values listed as the basis for a working growth curve interpretation. The erratic values for c_1 were probably due, in large part, to the inadequacy of the data from which they were derived. However, it must be kept in mind that the two soil groupings that were used were probably not based upon soils which were sufficiently similar in their behavior with respect to phosphate and potash.

There are some rather wide differences in variability of c_1 between the different extractants. It is of interest to note that the variability of c_1 for potash with Bray's extracting solution is low relative to the others on both Coastal Plains and Limestone Valley soil groups.

The data does not warrant any conclusions, based on c_1 variabilities, as to the relative adaptability of any of the extractants to a growth curve interpretation. However, from what has been observed in carrying the present correlation this far, it appears that the variability of the proportionality constant c_1 provides a valuable tool for establishing:

a. Whether or not a given extracting solution can be used in connection with a growth curve correlation.

b. What soil types and situations can be grouped together as "similar soils" for the purposes of a growth curve interpretation.

There is a wide variation of soil types in Virginia. In such an area it would seem essential first to compare the variability of c_1 values for several extracting solutions with one important crop on one major soil type in each soil province. After adequate data has been accumulated, the extracting solution with the lowest variability of c_1 should be selected as the basis for all future growth curve correlations.

Having selected the most adaptable extracting solution, additional calibration trials should be established on other important soil types in each soil province, using one important crop. After adequate data has been accumulated, c_1 values for P_2O_5 and K_2O may be established for that crop on each individual soil type. It will then be possible to group these soil types on the basis of workably similar c_1 values, setting up some maximum standard for variability of c_1 within a group of similar soils.

When the important agricultural soils have been grouped according to similarity of behavior with respect to K_2O and P_2O_5 for one major crop, it will then be possible to give attention to establishing correlations for other crops on these same soil groups.

In the present sample correlation, the variability of c_1 for K_2O with Bray's extractant was consistently low, as compared with the others, on both Limestone Valley and Coastal Plains soils. For this reason, soil test and c_1 values for Bray's solution will be used to illustrate the remainder of the steps involved in establishing a growth curve system of interpretation for K_2O. The variability of c_1 for P_2O_5 on Limestone Valley soils was too great with all extracting solutions to permit any correlation on these soils. The variability of c_1 for Hester II on Coastal Plains soils was sufficiently low to permit a sample correlation for P_2O_5 on these soils of the tidewater region.

Step 3. ---- Calculation of "percentage yield."

The "percentage yield," or "percentage sufficiency of the nutrient," is the yield on soil of b_1 test value without any of the nutrient applied as fertilizer, expressed as a percentage of the maximum yield on the same soil where adequate supplies of the nutrient are applied as fertilizer. The maximum yield for K_2O and P_2O_5 will vary in bushels or pounds per acre from field to field as a result of normal variations in the other limiting factors in soil productivity. However, if the maximum yield on individual fields is expressed as 100%, then the yield for any given b_1 value will be approximately a constant percent of the maximum at all locations within any group of similar soils.

The percentage yield for a given crop with respect to K_2O or P_2O_5 on a group of similar soils can be calculated directly from soil tests and the established c_1 values, using Equation #5. For purposes of illustration, the calculation is given here for one level of b_1 for K_2O with Bray's extractant:

$$\text{Log } (100-y) = \log 100 - c_1 b_1 \qquad \text{(Equation \#5)}$$

where y = percentage yield
c_1 = .0030 (the average c_1 value for Bray's solution on Limestone Valley soils)
b_1 = 200 pounds per acre (soil test value with Bray's solution)

$$\begin{aligned} \text{Log } (100-y) &= 2.0000 - (.0030 \times 200) \\ &= 2.0000 - .6000 \\ &= 1.4000 \\ 100-y &= 25 \\ y &= 75\% \end{aligned}$$

The implication of the above calculation is that on all soils included in the Limestone Valley group, a soil test for K_2O of 200 pounds per acre will permit only 75% corn yields if no potash is applied in fertilizer. In other words, a field with such a test which produces 75 bushels of corn per acre without potash is capable of producing 100 bushels if adequate K_2O is applied in the fertilizer. On the other hand, a field which produces only 15 bushels without K_2O can only produce 20 bushels with adequate K_2O, - unless other limiting factors are also taken care of.

In the first two columns of Tables 123 and 124 (pp. 270 and 271) are listed soil test readings for K_2O with Bray's extractant and the equivalent percentage yields calculated as above for Limestone Valley soils and Coastal Plains soils. In the first two columns of Table 125 (p.272) are listed soil tests for P_2O_5 with Hester II and the equivalent percentage yields for Coastal Plains soils. At the head of each column of soil tests (Column 1) in Tables 123, 124 and 125 is entered the average c_1 value used in the calculation.

In Table 123 a deficient soil supply of K_2O is indicated for the entire range of soil test values with Bray's extractant on Limestone Valley soils. This does not appear reasonable, although response to potash was obtained at the 400 pound level of soil K_2O on Dunmore silt loam in the data cited in Tables 6 and 7 (see last reference in Table 119). Quite probably the c_1 value (c_1 = .0030) used here is somewhat low. Bray has found c_1 = .0065 for K_2O on corn belt soils (11).

The lack of response expectations beyond the 160 pound level of soil K_2O on Coastal Plains soils suggests that c_1 = .0093 is too high (see Table 124). The same is probably true for the c_1 value (c_1 = .0402) used for P_2O_5 in determining percentage yield in Table 125. The soundness of the percentage yield concept will depend upon more accurate determination of c_1 than was possible with the data available here.

In application, it is usually found that both K_2O and P_2O_5 are limiting. In that case, the percentage yield is compounded for K_2O and P_2O_5 by multiplying their respective percentage yields. Thus, a test for K_2O of 80 pounds with Bray's extractant on Norfolk sandy loam would limit corn yields to 82% of maximum (Table 124). A test for P_2O_5 of 16 pounds with Hester II would limit yields to 77% (Table 125). The combined percentage yield for both K_2O and P_2O_5 would be 82% x 77%, or 63%.

<u>Step 4</u>. ---- Calculation of expected yield increases with adequate applications of K_2O and P_2O_5.

Although 100% is used as the maximum yield in calculating c_1, the theoretical requirement for achieving 100% yields by fertilizer applications of K_2O and P_2O_5 is large and indefinite. For this reason Bray (13) uses 98% as a practical maximum yield attainable by practical rates of fertilizer application. The calculation for establishing this 98% maximum yield for K_2O is as follows:

$$98\% \text{ of maximum yield} = \text{past yield without } K_2O \times \frac{98\%}{\text{percentage yield}}$$

In column 3 of Tables 123-125 are listed four unfertilized yield levels for each level of percentage yield. In column 4 is listed the calculated 98% maximum yield for each yield level in column 3. The difference between the past yield and the 98% maximum yield is listed in column 5. This is the expected yield increase if adequate K_2O or P_2O_5 is added in the fertilizer.

Past yield levels and maximum yields for K_2O or P_2O_5 are frequently determined by limiting factors other than the soil supply of either of these two nutrients. Thus the percentage yield concept permits predictions of crop response to K_2O or P_2O_5 which are tied in realistically with the currently realized productivity of individual fields, - much as dairy rations are established on the basis of the current production of individual cows.

The expected yield increases listed in column 5 of Tables 123-125 are for "adequate" supplies of K_2O or P_2O_5. The actual amount of fertilizer K_2O or P_2O_5 required to adequately complement the soil supply at any level of percentage yield will depend upon the form of the nutrient which is used. The amount of a given form of a nutrient required will depend upon the efficiency with which it can be utilized by a given crop on a given group of similar soils. The efficiency of each form of K_2O or P_2O_5 is characterized by its proportionality constant "c", to be determined as in Step 5.

Step 5. ---- Calculation of "c".

The efficiency of a given fertilizer nutrient varies with the crop, the form in which the nutrient is supplied, and the behavior of different soils with respect to the nutrient. It is necessary to correlate these variables in some manner before accurate fertilizer recommendations can be made. In Bray's system of interpretation this correlation is achieved by establishing the proportionality constant c for each form of the nutrient and for each crop on each group of similar soils.

The determination of c involves the establishment of fertilizer ratio experiments designed to give the following information for both

K_2O and P_2O_5:*

a. The yield where none of the nutrient is included in the fertilizer.

b. The <u>maximum</u> response to the nutrient, where the nutrient is the only variable.

c. At least one <u>intermediate</u> response to the nutrient at a rate of application <u>less</u> than that required for the maximum response.

The calculation of c again requires that the maximum yield be assumed to be 100%. Equation #4, is used (p. 241). The data for Frederick silt loam cited in Tables 62-63 provided two intermediate responses to K_2O for the calculation of c. This data is used in the following example:

$$\text{Log } (A-y) = \log A - (c_1b_1 + cx) \qquad \text{(Equation \#4)}$$

or

$$cx = \log A - \left[c_1b_1 - \log (A-y)\right]$$

Using the intermediate response for 300 pounds 4-12-12, we have:

x = 36# (K_2O applied as fertilizer)
A = 100% (Maximum yield: 29.7 bus. for 300# 4-12-24)
y = 94.3% (Yield for 36# K_2O: 28.0 bus.)
c_1 = .0030 (Average c_1 for Limestone Valley soils)
b_1 - 260# (Soil test for K_2O with Bray's extractant)

$$\begin{aligned} 36c &= \log 100 - \left[(.0030 \times 260) + \log (100 - 94.3)\right] \\ &= 2.0000 - (.7800 + \log 5.7) \\ &= 2.0000 - (.7800 + .7559) \\ &= .4641 \\ c &= .0129 \end{aligned}$$

---

* Note: These same ratio experiments will also provide the information for calculating c_1 (Step 2, p. 246).

Using the intermediate response for 300 pounds 4-12-18, we have:

$x = 54\#$ (K_2O applied as fertilizer)
$A = 100\%$ (Max. yield: 29.7 bus. for 300# 4-12-24)
$y = 98\%$ (Yield for 54# K_2O : 29.1 bus.)
$c_1 = .0030$ (Average c_1 for Limestone Valley soils)
$b_1 = 260\#$ (Soil test for K_2O with Bray's extractant)

$$
\begin{aligned}
54c &= 2.0000 - (.7800 + \log 2.0) \\
&= 2.0000 - (.7800 + .3010) \\
&= .9190 \\
c &= .0170
\end{aligned}
$$

Average c = (.0129 + .0170) + == .0150

In Tables 120 and 121 (pp. 267 and 268) are tabulated c values for K_2O on corn on Limestone Valley and Coastal Plains soils, using values for b_1 and c_1 secured with Bray's extractant. Also listed are the values for A, y, x, c_1 and b_1 which were used in the calculations. In Table 122 (p. 269) is a similar tabulation of c for P_2O_5 on Coastal Plains soils, based upon b_1 and c_1 values secured with Hester II extractant.

Not all of the experiments which were used for the calculation of c_1 in Tables 116 to 119 provided intermediate responses to K_2O or P_2O_5 which could be used for computing c. Also, the discrepancy between the average c_1 value for a soil group and the c_1 value calculated for individual experiments was so great that, in several instances, c could not be calculated from the average c_1 value. For these reasons only a few experiments could be used in computing c in Tables 120 to 123.

A glance at Tables 120 to 123 will reveal an extreme variability in the values for c. Obviously the much smaller variations in c_1 have been magnified in the values for c as computed from the same basic data. This fact emphasizes the importance to the growth curve interpretation of first establishing accurate values for c_1. Every step in experimental procedure must be carefully controlled. Of particular importance is the adequate statistical design of fertilizer ratio experiments to accurately define crop responses.

The growth curve concept implies that the response of a given crop to P_2O_5 or K_2O on similar soils is independent of other limiting factors within the range that those other factors are not acutely limiting. However, the range of responses to K_2O and P_2O_5 in the experiments on Coastal Plains soils was reduced by limiting supplies of nitrogen and in some cases of magnesium. On Limestone Valley soils moisture and lack of nitrogen reduced yields very severely. In several cases the maximum yield was obtained with the first increment of each nutrient, so that there was no basis for calculating c. In other cases, the differences between maximum and intermediate responses were so small as not to be significant. More than two replications of each treatment would have been required to establish the significance of such small differences in yield.

With the above considerations in mind, it is suggested that locations for growth curve correlation experiments be selected in advance. Soil samples should be taken and tested in advance of setting up the schedule of treatments for each location. The schedule of treatments should then be set up with a view to correcting acutely limiting factors other than P_2O_5 or K_2O. Nitrogen requirements, in particular, should be adequately met. This should extend the range over which crop yields are influenced by the availability of P_2O_5 or

K_2O. As a result, it should be possible to get a greater number of intermediate responses for the calculation of c. If combined with adequate statistical control, the increased differences in yield between treatments should make it possible to define yield levels for individual treatments more accurately. The accuracy of the determination of both c_1 and c will depend upon the accuracy of response determinations as well as upon the accuracy of the soil testing procedure that is used.

The values that were derived for c in the present correlation are not reliable. However, they will be used in Step 6 to illustrate the manner in which the fertilizer requirements for 98% maximum yield are calculated.

Step 6. ---- Calculation of the fertilizer requirement for 98% maximum yield.

After c_1 and c have been accurately determined, the amount of the nutrient needed as fertilizer to complement the available soil supply may be calculated by substitution in Equation #4.

The Average value for c on Limestone Valley soils (Table 120) gave extremely high fertilizer requirements. For this reason the average value for c (c = .0150) as determined in the sample calculation in Step 5 for Frederick silt loam was used to compute the K_2O requirements for Limestone Valley soils. The K_2O requirements are listed in column 7 of Table 123 (p. 270). The calculation for a soil test of 40# K_2O on these soils is as follows:

$$\text{Log } (A-y) = \log A - (c_1b_1 + cx) \qquad \text{(Equation \#4)}$$

or

$$cx = \log A - \left[c_1b_1 + \log (A-y)\right]$$

where

c = .0150 (Average c for Tables 62-63)
A = 100% (Theoretical maximum yield)
y = 98% (Practical maximum yield)
c_1 = .0030 (Ave. c_1 for Limestone Valley soils, Table 119)
b_1 = 40# (Soil test for K_2O with Bray's solution)

$$\begin{aligned} .0150x &= \log 100 - \left[(.0030 \times 40) + \log (100 - 98)\right] \\ &= 2.0000 - (.12000 + \log 2) \\ &= 2.0000 - (.1200 + .3010) \\ &= 1.5790 \end{aligned}$$

x = 105# (K_2O required in fertilizer to produce 98% maximum yield on soil with a test of 40# available K_2O)

The potash requirements for Coastal Plains soils listed in column 7 of Table 124 (p. 271) were calculated, using the average values for c_1 and c as determined in Tables 118 and 121 for Bray's solution. The phosphate requirements listed for Coastal Plains soils in Table 125 (p. 272) were based upon the average values for c_1 and c as determined in Tables 116 and 122 for Hester II extractant.

The potash requirements on Limestone Valley soils (Table 123) and the phosphate requirements on Coastal Plains soils (Table 125) are obviously too high. The requirements for potash on Coastal Plains soils (Table 124) are probably low. However, they will be used to supply the costs and returns information required to complete these tables.

Step 7. ---- Calculation of fertilizer costs and the value of expected yield increases.

Whether he is borrowing the money or paying cash out of his own pocket, the farmer must have assurance that his investment in fertilizer will return him cost plus interest plus increased handling charges. By converting the expected yield increases and the fertilizer requirements in Tables 123-125 to dollar values, a satisfactory estimate can be made regarding the point where returns will probably not cover costs.

The values listed in column 6 for the expected yield increases in column 5 were figured on the basis of $1.40 per bushel for corn. The cost of K_2O and P_2O_5 were figured at 7¢ per pound to arrive at the fertilizer costs listed in column 8 (Tables 123-125).

The costs and expected dollar returns as listed are, of course, subject to the same inaccuracies as the correlation upon which they are based, and are not to be taken at their face value. However, they do illustrate the fact that the break-even point for fertilizer costs and crop returns depends, not only upon the available soil supply of the nutrients to be purchased, but upon the realized production potential of a given field. This production potential may be limited by any number of factors other than the nutrients the farmer is thinking of buying.

Thus, in Table 125, a soil with a soil test of 24# per acre of P_2O_5 requires 97# of commercial P_2O_5 for maximum yields. This involves a cost of $6.79. On a field which has been producing only 20 bushels per acre in the past, the expected increase will pay for little better than a third of the fertilizer. On another field with the same test for P_2O_5, but with a history of 60-bushel corn yields, the expected increase in corn yields would probably bring a satisfactory net return.

3. Remarks relative to growth curve system of interpretation.

The system of growth curve interpretation that has been established in Illinois by Bray and his associates employs the percentage yield concept for determining the potash and phosphate requirements of individual crops in the manner illustrated in the correlation developed in the preceding pages and summarized in Tables 123-125 (pp.270-272). Individual crop requirements are then added together to give rotation requirements for standard rotations. Fertilizer recommendations are actually made on the basis of rotational requirements, rather than individual crop requirements. In other words, the total rotational requirement is so applied as to favor the crops with the highest requirements and which give the highest returns. Most of the potash is applied on corn and the legumes. The rotational requirement for phosphate is drill-placed for wheat and new seedings.

It is beyond the scope of the present study to attempt carrying the correlation to the rotational level. The procedure for doing so is described in a series of mimeographed circulars released by the Department of Agronomy of the Illinois Agricultural Experiment Station (see Lit. Cit.: 12).

There is one basic concept in the correlation as summarized in Tables 123 to 125 which will have to be modified in adapting the system to Virginia conditions. Fertilizer usage, particularly of potash, is much more widely established in Virginia than in Illinois. It would be very difficult to find a cultivated field in Virginia which does not receive phosphate and potash with nearly every crop. Thus the average yield of a given crop in the past <u>without</u> K_2O or P_2O_5 could not be determined directly from the yield history of a given field.

It would be necessary to calculate the yield <u>without</u> K_2O or P_2O_5, taking into account both past yields and past fertilization. This could be done, after c_1 and c have been established, by determining "percentage yield <u>with past fertilization</u>", as follows:

$$\text{Log } (A-y) = \log A - (c_1 b_1 + cx) \qquad \text{(Equation \#4)}$$

where

$A = 100\%$
c_1 = established proportionality constant for the nutrient in the soil.
b_1 = soil test on the field in question.
c = established proportionality constant for the nutrient in the fertilizer.
x = known past application of the nutrient for past yield levels.

Solve for y = percentage yield with past fertilization

Average yield in the past <u>without</u> K_2O (or P_2O_5) could then be figured by the following formula:

$$\text{Average yield in past without } K_2O = \text{Average yield with past fertilization} \times \frac{\text{Percentage yield without } K_2O}{\text{Percentage yield with past applications of } K_2O}$$

In the above formula the percentage yield without K_2O is calculated directly from soil tests and the average c_1 value established by calibration experiments (See Tables 116-119).

Obviously the growth curve interpretation cannot be established overnight. Its adaptation to Virginia conditions is complicated by a much greater diversity of soils than Bray has had to contend with in Illinois. Also, there is a greater diversity of crops in Virginia. A large number of experiments over a long period of years would be necessary to establish c_1 and c values for all major crops on the large number of agricultural soils in the state.

It is felt that the growth curve interpretation provides a means for resolving fertilizer practice based upon rapid soil tests to a simple formula which can be applied by a technician with limited short-course training, much as the basic principles of dairy feeding are applied by the dairy herd improvement tester when he recommends rations based upon butterfat tests and production records. In fact, the formulas involved are such that recommendations could be turned out by a simple electronic computer.

Such a system would greatly enhance the value of soil tests insofar as their influence on the efficient utilization of the major nutrients is concerned. Further, it would establish certain standards of expected response to phosphate and potash for certain soils. Thus, by a process of elimination, it would facilitate the diagnosis of other limiting factors.

If an experimental program for developing a growth curve correlation is initiated, the practical benefits of the research involved need not be postponed until the correlation is established. The fertilizer ratio experiments which are designed for the growth curve correlation may be used in the interim for increasing the accuracy and usefulness of the soil test correlation which is currently in use. As a matter of fact, all such data for a period of years should be correlated by each of the interpretation systems employed in this study so that final selection of a system of interpretation may be made on the basis of its proven merit. The adaptability of any specific extracting solution will also depend upon the system of correlation with which it will eventually be used.

A continuing research program such as the above is implicitly a part of any system of soil test interpretation, if the system is to maintain its usefulness. Research work must continue in all phases of the system. Testing methods and techniques are subject to continual improvement. Greenhouse work and field experiments must be conducted and individual crop responses on different soil types must be correlated with test values by both long chemical methods and rapid soil tests. Soil tests and fertilizer recommendations must be followed up to ascertain farmer compliance, actual crop yields, and farmer reaction. Such a rigorous research program is in large part responsible for the success of the Hester balance sheet interpretation as employed by the soil testing service of the Campbell Soup Co. in New Jersey (30).

Table 116 - Tabulation of c_1 values for phosphate with corn on Coastal Plains Soils.*

Reference: Basic data tables	Soil series	Response to phosphate: Adequate phosphate		No phosphate		Soil tests and c_1 values for the extractants which were used: Thornton		Morgan		Hester I		Hester II	
		Fertilizer ratio	Yield A (bu)	Fertilizer ratio	Yield y (bu)	Soil test b_1	c_1	Soil test b_1	c_1	Soil test b_1	c_1	Soil test b_1	c_1
28-29	Onslow	2-6-6	38.2	2-0-6	33.7	40	.0232	20	.0464	8	.1161	16	.0581
30-31	Norfolk	2-6-6	39.1	2-0-6	34.2	64	.0141	20	.0451	24	.0376	20	.0451
32-33	Lenoir	2-24-6	43.0	2-0-6	31.7	64	.0091	16	.0363	3	.1814	16	.0363
34-35	Onslow	2-6-6	46.7	2-0-6	42.2	64	.0159	8	.1270	3	.3175	32	.0318
36-37	Norfolk	2-24-6	64.0	2-0-6	55.0	112	.0077	16	.0533	24	.0355	48	.0178
38-39	Norfolk	2-12-6	45.1	2-0-6	39.0	96	.0091	16	.0543	16	.0543	20	.0434
22-23	Sassafras	12-12-12	69.4	12-0-12	55.1	28	.0245	26	.0264	23	.0298	14	.0490
Average values for c_1							.0148		.0555		.1103		.0402
Percentage variability of c_1							46.5%		59.5%		97.4%		32.5%

* Note: The proportionality constant c_1 was determined by substitution in Bray's (11, 13) working equation for the action of the growth factors:

$$\text{Log } (A-y) = \log A - c_1 b_1$$

Table 117 - Tabulation of c_1 values for phosphate with corn on Limestone Valley Soils.*

Reference: Basic data tables	Soil series	Response to phosphate: Adequate phosphate		Response to phosphate: No phosphate		Soil test and c_1 values for the extractants which were used. Thornton		Morgan		Hester I		Hester II	
		Fertilizer ratio	Yield A (bus)	Fertilizer ratio	Yield y (bus)	Soil test b_1	c_1	Soil test b_1	c_1	Soil test b_1	c_1	Soil test b_1	c_1
54-55	Frederick	4-12-6	33.1	4-0-6	28.1	6	.1368	6	.1368	32	.0257	12	.0684
56-57	Frederick	4-6-6	49.4	4-0-6	43.3	4	.2106	12	.0702	64	.0132	28	.0301
58-59	Hagerstown	4-24-6	21.4	4-0-6	15.9	4	.1475	0	∞	16	.0369	4	.1475
60-61	Frederick	4-24-6	38.1	4-0-6	28.1	8	.0726	4	.1428	6	.0968	4	.1428
62-63	Frederick	4-6-6	36.6	4-0-6	26.1	20	.0271	8	.0678	16	.0339	8	.0678
10	Berks	12-12-12	58.5	12-0-12	46.0	3	.2681	3	.2394	22	.0305	22	.0305
6-7	Dunmore	✝	✝	✝	✝	-	-	-	-	-	-	-	-
Average values for c_1							.1438		.1095		.0395		.0812
Percentage variability of c_1							61.1%		59.4%		74.2%		64.5%

* Note: The proportionality constant c_1 was determined by substitution in Bray's (11, 13) working equation for the action of the growth factors:

$$\text{Log}\ (A-y) = \log A - c_1 b_1$$

∞ Note: Zero soil test is not amenable to calculation of c_1 unless yield y is also zero.

✝ Note: Yield y was greater than for any phosphate treatment, - response not suitable for calculation of c_1 for phosphate.

Table 118 - Tabulation of c_1 values for potash with corn on Coastal Plains Soils.*

Reference: Basic data tables	Soil series	Response to potash: Adequate potash: Fertilizer ratio	Response to potash: Adequate potash: Yield A (bus)	Response to potash: No potash: Fertilizer ratio	Response to potash: No potash: Yield y (bus)	Soil tests and c_1 values for the extractants which were used: Bray: Soil test b_1	Bray: c_1	Morgan: Soil test b_1	Morgan: c_1	Hester I: Soil test b_1	Hester I: c_1	Hester II: Soil test b_1	Hester II: c_1
28-29	Onslow	2-12-18	38.6	2-12-0	30.7	80	.0086	80	.0086	30	.0230	30	.0230
30-31	Norfolk	2-12-12	39.4	2-12-0	31.7	100	.0071	100	.0071	75	.0095	60	.0118
32-33	Lenoir	2-12-12	39.4	2-12-0	37.3	160	.0080	120	.0106	60	.0212	60	.0212
34-35	Onslow	2-12-18	46.9	2-12-0	42.9	120	.0089	80	.0134	60	.0178	60	.0178
36-37	Norfolk	2-12-12	66.4	2-12-0	61.9	100	.0117	80	.0146	60	.0195	45	.0260
38-39	Norfolk	2-12-12	55.6	2-12-0	53.1	100	.0135	100	.0135	90	.0150	37	.0364
22-23	Sassafras	12-12-10	66.2	12-12-0	66.0	193	.0077	180	.0082	238	.0062	120	.0123
Average values for c_1							.0093		.0109		.0160		.0212
Percentage variability of c_1							25.2%		77.6%		38.7%		26.7%

* Note: The proportionality constant c_1 was determined by substitution in Bray's (11, 13) working equation for the action of the growth factors:

$$\text{Log }(A-y) = \log A - c_1 b_1$$

Table 119 - Tabulation of c_1 values for potash with corn on Limestone Valley Soils.*

Reference: Basic data tables	Soil series	Response to potash: Adequate potash		No potash		Soil tests and c_1 values for the extractants which were used.: Bray		Morgan		Hester I		Hester II	
		Fertilizer ratio	Yield A (bus)	Fertilizer ratio	Yield y (bus)	Soil test b_1	c_1	Soil test b_1	c_1	Soil test b_1	c_1	Soil test b_1	c_1
54-55	Frederick	4-12-6	33.1	4-12-0	25.0	140	.0044	100	.0061	75	.0082	60	.0102
56-57	Frederick	4-12-24	55.0	4-12-0	42.1	220	.0029	120	.0053	90	.0070	90	.0070
58-59	Hagerstown	‡	‡	‡	‡	—	—	—	—	—	—	—	—
60-61	Frederick	4-12-12	34.6	4-12-0	26.0	260	.0023	240	.0025	150	.0040	150	.0040
62-63	Frederick	4-12-24	29.7	4-12-0	25.1	260	.0031	200	.0041	135	.0060	120	.0068
10	Berks	12-12-20	54.5	12-12-0	40.5	265	.0022	270	.0022	98	.0060	180	.0033
6-7	Dunmore	2-12-20	77.3	2-12-0	68.9	400	.0024	280	.0034	180	.0054	200	.0048
Average values for c_1							.0030		.0039		.0061		.0060
Percentage variability of c_1							26.1%		39.0%		23.1%		45.2%

* Note: The proportionality constant c_1 was determined by substitution in Bray's (11, 13) working equation for the action of the growth factors:

$$\text{Log }(A-y) = \log A - c_1 b_1$$

‡ Note: Yield y was greater than for any potash treatment, - response not suitable for calculation of c_1 for potash.

Table 120 - Tabulation of c values for fertilizer potash on corn on Limestone Valley Soils, based upon soil test (b_1) and c_1 values secured with Bray's extracting solution.*

Reference: Basic data table	Soil series	Yield A (=100%)	Yield y	(A-y)%	Added K_2O for Yield y (=x)	c_1	b_1	c
54-55	Frederick	33.1 bu.	27.3 bu. 82.5%	17.5%	36#	.0030	140	.0095
56-57	Frederick	55.0 bu.	45.7 bu. 83.1%	16.9%	18#	.0030	220	.0062
			48.9 bu. 88.9%	11.1%	54#			.0055
60-61	Frederick	34.6 bu.	29.1 bu. 84.1%	15.9%	18#	.0030	260	.0010
62-63	Frederick	29.7 bu.	28.0 bu. 94.3%	5.7%	36#	.0030	260	.0129
			29.1 bu. 98.0%	2.0%	54#			.0170
10	Berks	54.5 bu.	47.0 bu. 86.2%	13.8%	50#	.0030	265	.0013
Average value for c								.0076

* Note: The proportionality constant c for fertilizer K_2O was determined by substitution in Equation #4, (p. 241):

$$\text{Log } (A-y) = \log A - (c_1 b_1 + cx)$$

where A = 100% (yield when K_2O is not deficient)
y = yield (expressed as percent of A) for x pounds per acre of K_2O applied as fertilizer.

Table 121 - Tabulation of c values for fertilizer potash on corn on Coastal Plains Soils, based upon soil test (b_1) and c_1 values secured with Bray's extracting solution.*

Reference: Basic data table	Soil series	Yield A (=100%)	Yield y	(A-y)%	Added K_2O for Yield y (= x)	c_1	b_1	c
28-29	Onslow	38.6 bu.	37.6 bu. 97.4%	2.6%	18#	.0093	80	.0467
30-31	Norfolk	39.4 bu.	38.8 bu. 98.5%	1.5%	18#	.0093	100	.0497
34-35	Onslow	46.9 bu.	45.8 bu. 97.7%	2.3%	18#	.0093	120	.0290
Average value for c								.0418

* Note: The proportionality constant c for fertilizer K_2O was determined by substitution in Equation #4, (p. 241):

$$\text{Log }(A-y) = \log A - (c_1 b_1 + cx)$$

where A = 100% (Yield when K_2O is not deficient)
y = yield (expressed as percent of A) for x pounds per acre of K_2O applied as fertilizer.

Table 122 - Tabulation of c values for fertilizer phosphate on corn on Coastal Plains Soils, based upon soil test (b_1) and c_1 values secured with Hester II extracting solutions.*

Reference: Basic data table	Soil series	Yield A (=100%)	Yield y	(A-y)%	Added P_2O_5 for Yield y (= x)	c_1	b_1	c
			32.2 bu. 74.9%	25.1%	18#			----
32-33	Lenoir	43.0 bu.	37.6 bu. 87.4%	12.6%	36#	.0402	16	.0071
			38.1 bu. 88.6%	11.4%	54#			.0056
38-39	Norfolk	45.1 bu.	39.7 bu. 88.7%	12.0%	18#	.0402	20	.0065
22-23	Sassafras	69.4 bu.	60.5 bu. 87.2%	12.8%	30#	.0402	14	.0110
Average value for c								.0076

* Note: The proportionality constant c for fertilizer K_2O was determined by substitution in Equation #4, (p. 241):

$$\text{Log } (A-y) = \log A - (c_1 b_1 + cx)$$

where A = 100% (yield when K_2O is not deficient)
y = yield (expressed as percent of A) for x pounds per acre of K_2O applied as fertilizer.

Table 123 - Potash requirements for corn on Limestone Valley soils as calculated by the growth curve correlation of data cited in Tables 118-122.

1	2	3	4	5	6	7	8
Available K_2O by Bray's extractant	Percentage yield without K_2O	Average Yield in the past without K_2O	98% of Maximum Yield with practical applications of K_2O	Expected Yield Increases for K_2O added in fertilizer	Value* of Expected Yield Increases	Pounds/Acre K_2O needed for 98% of maximum yield	Cost of* K_2O needed in fertilizer
c_1 = .0030						c = .0150	
40#	24%	10 bus.	41 bus.	31 bus.	$43.40	105#	$7.35
		15 "	62 "	47 "	65.80		
		20 "	82 "	62 "	86.80		
		25 "	103 "	78 "	109.20		
80#	42%	10 "	23 "	13 "	18.20	97#	$6.79
		20 "	46 "	26 "	36.40		
		30 "	69 "	39 "	54.60		
		45 "	104 "	59 "	82.60		
120#	56%	10 "	18 "	8 "	11.20	89#	$6.23
		20 "	36 "	16 "	22.40		
		40 "	72 "	32 "	44.80		
		60 "	108 "	48 "	67.20		
160#	67%	20 "	30 "	10 "	14.00	81#	$5.67
		30 "	45 "	15 "	21.00		
		50 "	75 "	25 "	35.00		
		70 "	105 "	35 "	49.00		
200#	75%	20 "	26 "	6 "	8.40	73#	$5.11
		40 "	52 "	12 "	16.80		
		60 "	78 "	18 "	25.20		
		80 "	104 "	24 "	33.60		
240#	81%	30 "	36 "	6 "	8.40	65#	$4.55
		40 "	48 "	8 "	11.20		
		60 "	72 "	12 "	16.80		
		90 "	108 "	18 "	25.20		
320 #	89%	30 "	33 "	3 "	4.20	49#	$3.43
		40 "	44 "	4 "	5.60		
		60 "	66 "	6 "	8.40		
		95 "	105 "	10 "	14.00		
400#	94%	40 "	41 "	1 "	1.40	33#	$2.31
		60 "	62 "	2 "	2.80		
		80 "	83 "	3 "	4.20		
		100 "	104 "	4 "	5.60		

* Note: Following market values were assumed: Corn - $1.40 per bushel; K_2O - 7¢ per pound

Table 124 - Potash requirements for corn on Coastal Plains soils as calculated by the growth curve correlation of data cited in Tables 118-122.

1 Available K_2O by Bray's extractant	2 Percentage yield without K_2O	3 Average Yield in the past without K_2O	4 98% of Maximum yield with practical applications of K_2O	5 Expected Yield Increases for K_2O added in fertilizer	6 Value* of Expected Yield Increases	7 Pounds/Acre K_2O needed for 98% of maximum yield	8 Cost of* K_2O needed in fertilizer
c_1 = .0093		10 bus.	17 bus.	7 bus.	$ 9.80	c = .0418	
		20 "	34 "	14 "	19.60		
40#	58%	40 "	68 "	28 "	39.20	32#	$2.24
		60 "	102 "	42 "	58.80		
		20 "	24 "	4 "	5.60		
		40 "	48 "	8 "	11.20		
80#	82%	60 "	72 "	12 "	16.80	23#	$1.61
		80 "	96 "	16 "	22.40		
		20 "	21 "	1 "	1.40		
		40 "	43 "	3 "	4.20		
120#	92%	60 "	64 "	4 "	5.60	14#	$ .98
		90 "	96 "	6 "	8.40		
		20 "	20 "	none	-----		
		40 "	40 "	none	-----		
160#	97%	60 "	61 "	1 "	1.40	5#	$ .35
		90 "	91 "	1 "	1.40		

* Note: Following market values were assumed:

Corn - $1.40 per bushel
K_2O - 7¢ per pound

Table 125 - Phosphate requirements for corn on Coastal Plains soils as computed by the growth curve correlation of data cited in Tables 118-122.

1 Available K_2O by Bray's extractant	2 Percentage yield without K_2O	3 Average Yield in the past without K_2O	4 98% of Maximum yield with practical applications of K_2O	5 Expected Yield Increases for K_2O added in fertilizer	6 Value* of Expected Yield Increases	7 Pounds/Acre K_2O needed for 98% of maximum yield	8 Cost of* K_2O needed in fertilizer
c_1 = .0402		5 bus.	20 bus.	15 bus.	$ 21.00	c = .0076	
		10 "	41 "	31 "	43.40		
3#	24%	15 "	62 "	47 "	65.80	208#	$14.56
		25 "	102 "	77 "	107.80		
		10 "	19 "	9 "	12.60		
		20 "	38 "	18 "	25.20		
8#	52%	30 "	57 "	27 "	37.80	181#	$12.67
		50 "	95 "	45 "	63.00		
		20 "	26 "	6 "	8.40		
		30 "	39 "	9 "	12.60		
16#	77%	50 "	65 "	15 "	21.00	139#	$ 9.73
		75 "	98 "	23 "	32.20		
		20 "	22 "	2 "	2.80		
		40 "	44 "	4 "	5.60		
24#	89%	60 "	66 "	6 "	8.40	97#	$ 6.79
		90 "	99 "	9 "	12.60		
		20 "	20 "	none	------		
		40 "	41 "	1 "	1.40		
32#	95%	60 "	62 "	2 "	2.80	54#	$ 3.78
		90 "	93 "	3 "	4.20		

* Note: Following market values were assumed:

Corn - $1.40 per bushel
K_2O_5 - 7¢ per pound

PART V

SUMMARY AND CONCLUSIONS

Four major objectives were undertaken in the present study. The conclusions drawn from the experimental work which was undertaken during the three years of this project are here summarized as they bear upon these objectives.

Objective 1. - To select an extracting solution capable of removing significant fractions of the major crop nutrients from several important agricultural soils in Virginia that vary rather widely chemically and physically:

(a) The principle of fractional extraction does not appear to be sound. Only an empirical correlation can be established between crop response and a soil test which reveals only a fraction of the available soil supply of a nutrient. Such a correlation may change with marked changes in genetic crop materials or cultural practices.

(b) It appears that the long time usefulness of a given correlation may be better maintained if an extracting procedure is used which measures the total soil supply of the form, or forms,of each nutrient which are most effective in crop growth. Literature is reviewed which cites total exchangeable K_2O, and adsorbed and acid soluble P_2O_5 as the important forms of these nutrients from the standpoint of plant nutrition. The importance of measuring adsorbed phosphorus as well as acid-soluble forms may be inferred from the data reported here.

(c) Bray's sodium perchlorate removed larger amounts of potassium from the soils studied than the other extractants which were used in this investigation. With certain modifications, the sodium perchlorate solution appears to be the most promising of these extractants for measuring total exchangeable K_2O, MgO and CaO in Virginia soils.

(d) None of the extracting solutions studied adequately measure adsorbed P_2O_5. Certain considerations to be kept in mind in selecting or developing an extractant for phosphate are suggested.

(e) The absorption solution which was used involved two serious flaws in its chemical make-up. Suggestions are given for correcting these. However, the adaptability of an absorption technique to general field crops is questioned.

<u>Objective 2.</u> - To establish rapid chemical testing procedures, with particular attention to simplified reading methods:

(a) The testing procedures which were used for K_2O, P_2O_5 and MgO were found quite satisfactory from the standpoint of consistency of readings on duplicate soil extractions.

(b) Readings with the calcium test were extremely erratic. The data indicated that this was due to pH relationships involved in both the extracting solutions and the testing reagents. Certain considerations to be kept in mind in devising an extracting solution and a testing reagent for calcium are outlined. It is felt that the extracting solution so developed for calcium will also prove adequate for potash and magnesium.

(c) For greater accuracy in calibration studies it is suggested:

(1) That soil samples be weighed rather than measured volumetrically.

(2) That larger samples be extracted.

(3) That photometric reading methods be substituted for visual readings.

(d) For simplicity in the field it is suggested:

(1) That volumetric measurement of soil samples and visual reading methods will be adequate.

(2) That permanent standards be developed in plastic by a process developed since the laboratory investigations reported here were carried on (36).

(3) That such working standards be graduated closely enough to permit roughly quantitive interpretation and yet maintain graduations sufficiently separate and distinct to permit an operator with average vision to make positive comparisons with test solutions. Five or six graduations over the reading range for each nutrient are suggested for practical use.

Objective 3. - To calibrate soil test results against crop responses to fertilization and establish a scheme for interpreting soil tests in terms of fertilizer recommendations:

(a) The accuracy of any system of calibration of soil tests depends not only upon the accuracy of the soil tests, but upon the accuracy of response determination, as well. The accuracy of response determination in the experimental data available to the present study was not adequate for more than tentative calibration by any of the systems of interpretation which were tried.

(b) An adequate correlation by any system of interpretation cannot be based upon a single year's experimental results.

(c) Effective correlations can be developed only from experiments specifically designed to eliminate acutely limiting factors other than the specific nutrients for which correlation is sought. Suggestions are made for consideration in designing calibration experiments.

(d) It appears that the usefulness of the high-low-medium interpretation and of the interpretation based upon simple response or non-response is dependent upon the skill and experience of the individual who makes the interpretation.

(e) The balance-sheet interpretation must, of necessity, be based upon a fractional extraction. It does not appear that such a correlation can be made for potash on the heavy soils of the Limestone Valley. Where such a correlation can be made, it must be strictly empirical and subject to change, as already suggested.

(f) The growth curve interpretation would appear to provide a means for resolving fertilizer practice based upon rapid soil tests to a simple formula which could be applied by a technician with limited short-course training, or by a machine calculation. It is felt that it has sufficient merit for thorough investigation under Virginia conditions.

(g) The final selection of a system of soil test interpretation can be made on the basis of proven merit by a comparative correlation, employing the several systems on identical data over a period of years.

(h) The continued usefulness of any given system of interpretation can only be maintained by continued research into all phases of the system.

Objective 4. - To evaluate in a preliminary manner the use of plant tissue testing as a diagnostic technique in conjunction with soil testing:

(a) In calibration studies, plant tissue tests afford an invaluable check upon the adequacy of the fertilizer nutrients included in the schedule of treatments. They also give indirect evidence of the presence of limiting factors other than the ones directly under consideration.

(b) In follow-up studies, which are essential to maintain the usefulness of fertilizer recommendations based upon any system of soil test interpretation, plant tissue tests would appear to have definite application.

PART VI

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PART VII

VITA

Name: Arthur Ripatte Wolcott

I was born, January 10, 1918, in Missaukee County, Michigan. I grew up in an urban-rural background at Lake City, Michigan, where I attended the public schools, and took four years of vocational agriculture in high school.

Following two years of a liberal arts curriculum at Suomi College, Hancock, Michigan, I transferred to the School of Agriculture, Michigan State College, where a B. S. degree in Soils was awarded in March, 1940. With benefit of the fellowship sponsored by the American Potash Institute and under which the present investigation was undertaken, I entered Virginia Polytechnic Institute in June, 1941, enrolled in a course of studies directed towards a master's degree in Agronomy. This work was disrupted by a period of service in the U. S. Naval Reserve and a year during which I undertook the operation of the family farm at Lake City, Michigan.

During the winter term of 1946-47, I completed residence work at V. P. I. In April, 1947, I accepted a position as research specialist in Farm Crops and Soils Science at the Upper Peninsula Sub-station of the Michigan State College Agricultural Experiment Station at Chatham, Michigan, in which capacity I am employed at the present time.

I was married in June, 1940. We have three children, ages 7, 5 and 2.

Arthur R. Wolcott

PART VIII

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A. R. Wolcott

APPENDIX I

INDEX TO TABLES AND FIGURES

ABSTRACT

Wolcott, A. R. Investigation of the principles of rapid soil tests for available potash and other plant nutrients of Virginia soils: III. Selection, development and calibration of rapid chemical soil tests for available potassium, phosphorus, calcium and magnesium. Thesis submitted to the Graduate Faculty of the Virginia Polytechnic Institute in candidacy for the degree of Master of Science in Agronomy. June, 1951.

Four rapid soil test extracting procedures for potassium, phosphorus, calcium and magnesium, and one absorption procedure for potassium and phosphorus were compared. The soils studied represented important agricultural soils in the Coastal Plains, Piedmont and the Limestone Valley areas of Virginia. Extracting and testing procedures were evaluated on the basis of laboratory performance and by correlation with supplemental yield data from 49 field experiments. Four systems of soil test interpretation were applied in correlating soil tests with crop response to current fertilizer applications.

It appeared that only an empirical correlation could be made between crop response and a soil testing procedure which attempts to simulate seasonal crop removal of soil nutrients. A more basic, more tenable correlation appeared possible with soil testing procedures which approach <u>total</u> measurement of exchangeable K_2O, CaO and MgO, and adsorbed <u>and</u> acid soluble P_2O_5. With certain modifications, Bray's sodium perchlorate solution was the most promising of the extractants tested for measuring total exchangeable K_2O, CaO and MgO. Neither the acetate or the chloride ion adequately measured adsorbed P_2O_5. No other anions were tested in the phosphorus extractions. It appeared questionable that absorption techniques could be adapted to a correla-

tion with the response of general field crops to fertilizer applications.

The chemical testing procedures used for determining K_2O, P_2O_5 and MgO in the soil extracts were found quite satisfactory. Calcium tests on soil extracts were erratic. The variability of calcium readings appeared to result from pH relationships involved both in the extraction and in the developed test solutions.

The "high-low-medium" interpretation and the interpretation based upon simple response or non-response permitted only a general correlation to be made. Their potential value appeared to be chiefly that of giving support to fertilizer recommendations arrived at on the basis of more specific information regarding the soil type, soil pH, the crop to be grown, the location, and the cropping and fertilization history of the field.

The balance sheet interpretation must, of necessity, be based upon fractional extraction. Such a correlation must be strictly empirical. A balance sheet correlation, using any of the extracting procedures that were tested, did not appear to be possible for corn on the heavy soils of the Limestone Valley.

The growth curve interpretation as developed by Bray in Illinois appeared most promising as a means for resolving fertilizer practice based upon rapid soil tests to a simple formula which takes into consideration current soil productivity and the specific behavior of specific crops to soil and fertilizer nutrients in specific soils. The accurate determination of the constants involved will permit a quantitative relationship between soil tests and fertilizer recommendations.