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SOIL TEST INTERPRETATION STUDIES: LABORATORY AND POTTED PLANT

INTERNATIONAL Soil Testing

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Appreciation is expressed to S.I.P.A. and the Agrarian University of La Molina, Perú for their cooperation in conducting the soil test interpretation studies. Some of the data from these studies are reported in this bulletin.

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SOIL TEST INTERPRETATION STUDIES: LABORATORY AND POTTED PLANT

by

D. L. Waugh

J. W. Fitts

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Soil test results must be correctly interpreted before the information can be used satisfactorily as a guide in the use of fertilizers and other soil amendments. It is the purpose of this bulletin to present simplified methods of obtaining data for use in the interpretation of soil tests and thereby help in the fertilizer recommendations made to farmers.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
SAMPLING SOILS FOR LABORATORY AND POTTED PLANT STUDIES	2
Selection of Soils	2
Taking the Samples	3
Sample Preparation	5
LABORATORY STUDIES	7
Routine Analyses	7
Fixation of Applied Phosphorus	8
Procedure	8
Plotting the Results	10
Selecting "X" Value	10
POTTED PLANT STUDY	12
Containers and Sample Size	12
Overcoming Soil Acidity	13
The Amount of Water to Add to the Soils	13
Soil Phosphorus Interpretation Study	14
Treatments and Replications	15
Procedure	15
Calculation of Results	20
Interpretation of Data	20
Readily Available Potassium in Soil	23
Treatments and Replications	23
Procedure	23
Calculation of Results	26
Interpretation of Data	26
Measuring Potassium Supplying Characteristics of Soils Through Exhaustive Cropping	27
Procedure	29
Calculation of Results	29
Interpretation of Data	31

SOIL TEST INTERPRETATION STUDIES: LABORATORY AND POTTED PLANT

D. L. Waugh and J. W. Fitts

INTRODUCTION

Soil analysis is a valuable source of information for use in soil management; however, the analysis must be correctly interpreted to be useful. Fitts and Nelson[1/] stated that some of the more important objectives of soil testing are: (a) To group soils into classes for the purpose of suggesting fertilizer and lime practices; (b) To predict the probability of getting a profitable response to the application of plant nutrients; (c) To help evaluate soil productivity; and (d) To determine specific soil conditions which may be improved by the addition of soil amendments or cultural practices. The greatest use of soil testing today is for guidance in the use of fertilizers and lime.

The interpretation of soil analysis is a distinct and very important part of a soil testing program. The great number of types of soil, the wide range in climatic conditions, and the large variety of crops grown in most countries dictate that a considerable amount of research is needed for the correct interpretation of soil tests. The purpose of this bulletin is to outline some procedures for obtaining soil samples and to suggest some methods for conducting laboratory and potted plant studies to obtain data for use in the interpretation of soil test results as a basis for making fertilizer recommendations. The studies are designed especially for interpretation of phosphorus and potassium soil test results, but similar

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1/ The Determination of Lime and Fertilizer Requirements of Soils Through Chemical Tests. Advances in Agronomy 8:241-282. 1956.

procedures may be followed in studying other nutrient elements, provided that specific characteristics of the element in question (including interactions with other elements) are considered.

In obtaining data for soil test interpretation, the philosophy is followed that certain information about the soil should be obtained first in the laboratory, and then tested in potted plant studies. Data from the potted plant studies will aid in the selection of a suitable method of analysis and indicate critical levels of a nutrient in the soil below which proper use of fertilizer containing that element should be profitable. The final test of these established critical levels must then be made with carefully conducted field trials.

SAMPLING SOILS FOR LABORATORY AND POTTED PLANT STUDIES

Selection of Soils

The usefulness of the interpretation studies will depend largely on the extent to which the soils represent soil conditions which will be included in a soil testing program. Soil testing will be called upon to provide information regarding soil fertility for areas which may vary from agriculturally developed soils to virgin soils being considered for colonization projects; from high producing, heavily fertilized soils to low producing soils never having received fertilizers. Information on problems other than fertility such as erosion, poor drainage, salinity, extreme acidity, etc., can be obtained also through soil tests. Therefore, in planning the interpretation studies it is essential to know the range of the soil conditions which will be encountered in the soil testing program, and to know the geographic areas which will be represented. Obviously, the

more important cultivated soils should be among the first to include in the study. In some regions where colonization plans are being developed, a high priority may be given to sampling the major soil areas to be brought under cultivation.

Soil sampling for the interpretation of phosphorus and potassium levels should include, to the extent possible, a range in fertility status. Some samples must be selected which are below the critical level where a fertilizer containing the element in question is needed and some samples must be above it. General crop growth characteristics, deficiency symptoms, past history and previous experimental field plots or demonstrations can be used as guides in selecting soils of differing levels of fertility. Soil surveys are extremely helpful in selecting soils to be included in the fertility studies and should be used if they are available.

In selecting samples for the initial fertility interpretation studies, care should be taken to avoid adverse areas, such as saline, alkali, or extremely acid conditions. If, however, the soils with the adverse condition occupy a considerable area and are important agriculturally, then they should be included in the study, but with the realization that the adverse condition must be corrected in order to obtain the maximum benefit from the fertilizers.

Taking the Samples

Once these general factors regarding soil sampling have been carefully considered, geographic locations can be astutely chosen. The following guidelines should be used in selecting local sampling sites:

1. Select major soil types if the region has been surveyed; if no soil map is available, select soils of similar characteristics that are extensive in the area and which are suitable for cultivation.

2. The sampling site should be uniform and large enough so that a field research study can be conducted on the area at a later time. If there are good experimental plots with a high degree of uniformity already established in the area, the check plots (without P or K added) make excellent sampling sites.

3. Do not sample from areas or plots which have recently received phosphorus or potassium. Recently fertilized soils are generally variable in fertility and the fertilizer will not have yet reached a state of equilibrium. Fields which have had fertilizers added as a regular management practice for several years may have attained a high nutrient level and can be used to obtain samples above the critical level.

4. Obtain the sample by using a spade or shovel to cut vertical slices of soil about three centimeters thick and to a depth of 15 to 20 centimeters (about the normal depth of plowing). Do not include any of the subsoil in the sample; do not sample the subsoil. Take slices from a large number of separate points until at least 40 kg of air-dry soil is collected. Larger samples are desirable if the cost of transporting the soil to the laboratory is not prohibitive. It is also recommended that about 200 kg of soil be collected from each of two or three of the most important soil groups for use as control samples.

5. Collect as many samples as deemed necessary to represent the soils to be studied. If more samples are collected than can be handled in a single potted plant study, they may be separated into two or more groups for future studies.

Sample Preparation

The bulk samples must be thoroughly mixed before removing subsamples in order to eliminate great variation in the analytical results. Pass the soil sample through a wire screen of about 6 to 10 mm size openings. This screening will break up the clods and separate foreign material (which should be discarded) but will not completely break down the soil structure. Next, air-dry the sample by spreading it on a clean surface (a plastic sheet or heavy wrapping paper are excellent for this drying procedure). After air-drying, mix the soil thoroughly by rolling back and forth (at right angles) on a heavy canvas or plastic sheet.

An excellent soil mixer can be easily constructed from a 30 to 50 gallon barrel as shown in Figure 1. Pass a rod diagonally through the barrel and mount on two vertical stands. An opening with a hinged door is made near one end of the barrel for filling and emptying. The barrel is turned by a crank or motor attached to the rod. The sample may be stored in a metal can, or in a large plastic bag placed inside a heavier bag or container for added strength.

Soil passed through the 6 mm screen will be sufficiently fine to use in potted plant studies but, for laboratory analyses where smaller samples are involved, finer screening will be necessary. To obtain a representative subsample for analytical purposes, take 40 to 50 ml of soil from 10 to 12 places in the bulk sample and pass through a 2 mm screen (total volume of subsample will be 400 to 500 ml). Mix thoroughly by rolling at right angles on a clean piece of cloth, wrapping paper, or plastic sheet.

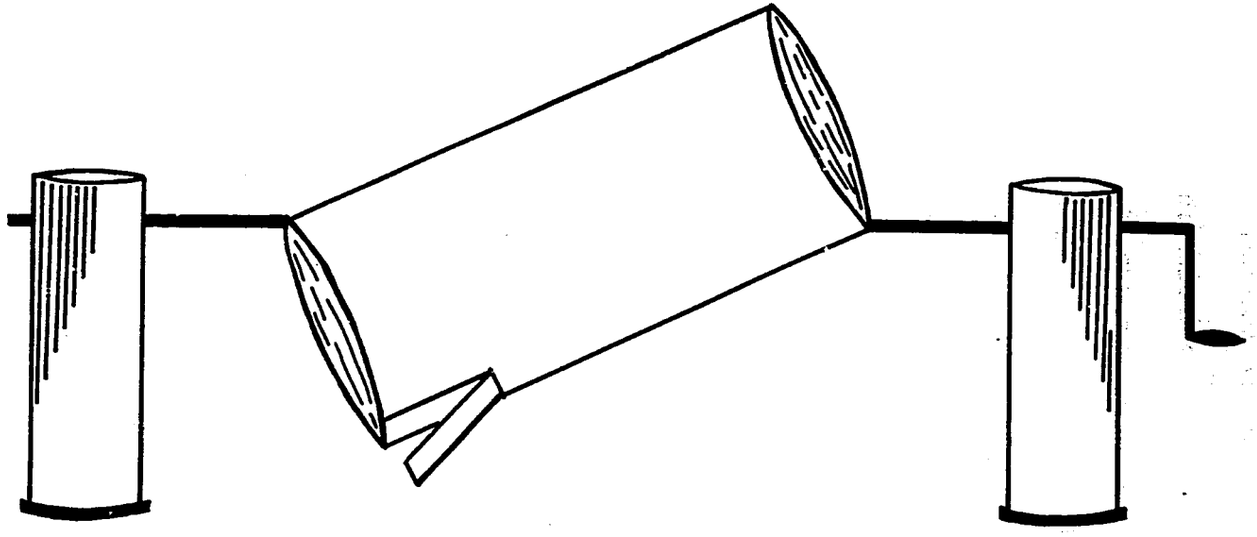

Figure 1. A barrel mixer for soil samples.

LABORATORY STUDIES

Routine Analyses

Before initiating potted plant studies, it is desirable to gain as much information about the soils as possible. The quickest and most economical way to do this is through routine laboratory analyses. These analyses should include:

1. pH measurements. Glass electrode meter using a soil to water ratio of 1:1, 1:2 or 1:2.5.
2. Available phosphorus. Extractant (or extractants) that is likely to give best results with soils under study.
3. Exchangeable potassium. Neutral normal ammonium acetate is usually considered to be the standard extractant for determining exchangeable potassium. (A flame photometer is generally used to measure the potassium extracted.)
4. Readily oxidizable organic matter. The modified Walkley-Black procedure using sodium dichromate and sulfuric acid.
5. Aluminum for acidity determination and lime requirement. Extracted with 1 N KCl and titrated with NaOH using phenolphthalein as indicator.
6. Soluble salts. For routine analysis, the salts can be determined by conductivity measurements using a soil to water ratio of 1:1, 1:2 or 1:5.
7. Free calcium carbonate. Soils with a pH of 7.0 or above should be tested with dilute HCl to determine the presence of free calcium carbonate.

8. Exchangeable calcium and magnesium. These elements may be determined either by EDTA titration or by direct reading with an atomic absorption spectrophotometer.

The following references may be used for detailed instruction of the routine procedures presented above:

Methods of Soil Analysis, Vol. 1 and 2, American Society of Agronomy, Madison, Wisconsin.

Soil Chemical Analysis - M. L. Jackson, Prentice-Hall Inc.

Saline and Alkali Soils - U.S.D.A., Agriculture Handbook No. 60.

Fixation of Applied Phosphorus

Phosphate fertilizers undergo various reactions when mixed with soils. The products formed in the soil usually are much less available to plants than the fertilizer phosphate added. Thus the soil in a sense competes with the plant for the phosphate applied in the fertilizer. A knowledge of the amount of phosphate that is likely to be fixed by the soil is of great importance in making soil test interpretation and fertilizer suggestions.

Soils vary considerably in the amount of applied phosphorus which is fixed in a form that is not readily available to plants. This study is designed to aid in estimating the rate of phosphorus to apply to the soil in order that sufficient phosphorus will be available for plant growth. The information from this study will be used to determine the amounts of phosphorus to apply in the potted plant studies.

Procedure

1. Prepare P solutions as follows:

   A. Stock Solution - 2500 ppm P. Dissolve 9.44 g $Ca(H_2PO_4)_2$ in water

and dilute to one liter.

B. Diluted P solutions for adding to soils. These solutions are prepared from the stock solution A by diluting the volumes shown in Column 3 of Table 1 to 100 ml.

Column 4 of Table 1 indicates the ppm of P in the diluted solution. Column 2 shows the ppm in the soil when 2 ml of the diluted solution B are added to 5 ml of soil.

Table 1. Preparation of P solution for fixation studies

Treatment No.	Concentration of P in soil 2 ml solution B to 5 ml soil	B Solution volume of A solution to dilute to 100 ml	B solution Concentration
	ppm	ml	ppm
1	0	0	0
2	50	5	125
3	100	10	250
4	150	15	375
5	200	20	500
6	250	25	625
7	300	30	750
8	400	40	1000
9	500	50	1250
10	600	60	1500

2. Measure 5 ml of soil from each sample and place in a suitable extraction bottle. The extraction procedure used in the routine analysis

may be used for removing phosphorus from the soil samples after they have been incubated. In addition to the 10 treatments for each soil indicated in Table 1, one bottle should be prepared for a control sample during the extraction procedure (Part 4 below).

3. Carefully pipette 2 ml of the B solution directly on the soil in the extraction bottles taking care to wet the soil uniformly. Repeat this process for each of the 10 treatments in Table 1. For the 0 treatment add 2 ml of water. Cover the extraction bottles so that the samples remain moist.

4. Incubate the treated samples for four days at room temperature. After the incubation period, proceed directly with the extraction of the moist samples and determine P according to the procedure selected for analysis of soil for phosphorus. Add one control sample for each tray of 10 treated samples.

Plotting the Results

The amount of calcium phosphate that has reacted with the soil constituents can be readily observed by plotting the P extracted by soil test vs. the amount of P applied. The results of P fixation studies on three soils of Perú are shown in Figure 2 and illustrate the types of curves that are likely to be obtained.

Selecting "X" Value

The point where extractable P increases abruptly as shown with sample 3 in Figure 2 is selected as value X. Soils which fix little or no phosphorus such as samples 1 and 2 may be assigned an X value of 50 or 100 ppm. The X value is an approximation of the amount of P required to more than overcome the effect of fixation of P and thus at this value there will be an increase

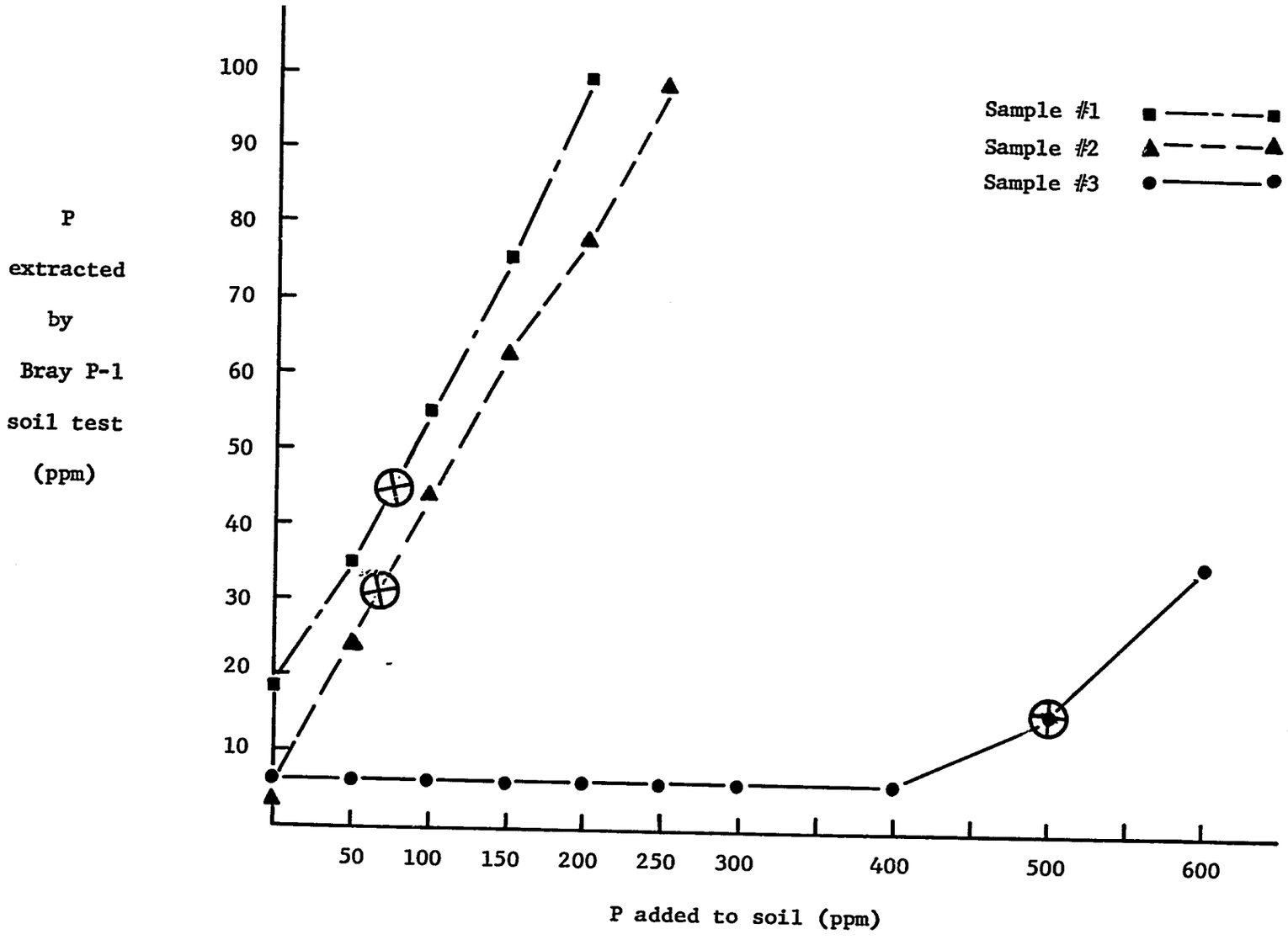

Figure 2. The amount of P extracted by soil test in relation to the rate of P applied on three soils of Perú. (Data in thesis from research conducted in SIPA by Müeller for Ing. Agrónomo degree, Universidad Agraria, La Molina, Perú, 1966. In Press.)

in plant-available phosphorus. Use the X value as a guide in determining the rates of P to apply in the subsequent potted plant study.

POTTED PLANT STUDY

The interpretation of soil analysis relates plant growth response from the application of a given element, such as P or K, to the amount of the same element extracted from the soil. This relationship facilitates the selection of soil testing methods which accurately predict whether or not a profitable response from application of fertilizer is likely at a given soil test value. Since factors influencing plant growth, such as temperature, light, day length, wind, relative humidity, insects, diseases, and weeds, can be controlled much more readily in potted plant studies than in field experiments, these carefully controlled studies should precede field trials.

Containers and Sample Size

There are several types of containers that can be used for these studies. The more popular ones are metal cans lined with plastic cloth, and plastic or clay pots. All containers should have holes in the bottom to allow free movement of air and drainage of water in the event of accidental overwatering. The size of the soil sample used in potted plant studies differs among various research workers, but a volume of 2000 ml of soil will hold sufficient moisture so that control of the water in the soil offers no great problem.

The soil sample may be either measured or weighed (2000 ml or 2 kg). Since plants grow in a given volume of soil and since fertilizers or lime are applied to volumes of soil, it is suggested that volume measurements be used

in a potted plant study. This alleviates the problem of having pots filled to differing heights or even having different sizes of pots in soils of extreme differences in apparent density. However, the volume weight of most screened, air-dried soils will not vary greatly.

Overcoming Soil Acidity

All soils to be used in the studies that show titratable acidity (from the test for aluminum) should be limed. The amount of $Ca(OH)_2$ to apply can be calculated as follows:

me $Ca(OH)_2$ required per 100 ml soil = me aluminum x 2

Apply the $Ca(OH)_2$ by spreading the soil on a clean piece of cloth, plastic sheet or heavy wrapping paper and uniformly add the $Ca(OH)_2$ as a suspension. Mix the soil by rolling at right angles (by grasping the corners of the sheet). Add sufficient water to bring soil to field capacity and allow the $Ca(OH)_2$ to equilibrate with the soil for at least one week before proceeding with the plant studies.

The Amount of Water to Add to the Soils

In potted plant studies the soils usually are wetted to the "field capacity". Suitable measurements can be made for each soil to determine its capacity to hold water; however, the amount of water needed for potted plant studies can be estimated sufficiently accurate on the basis of soil texture.

The amount of water to add to air-dry soils of various textures to bring the moisture level to approximate field moisture capacity is shown in Table 2.

Table 2. Approximate field moisture capacity in disturbed soil according to texture

Apparent Texture (finger test)	Approximate Field Moisture Capacity	Apparent Texture (finger test)	Approximate Field Moisture Capacity
	%		%
sands	10	silt loams	28
sandy loams	15	silty clay loams	32
loams	20	silty clays	35
silts	25	clays	40

Soil Phosphorus Interpretation Study

In the interpretation of soil tests the results are usually classed into three groups: low, medium or high. Soils are placed in the low group when the probability is high that a profitable response will be obtained from the application of a fertilizer containing the element in question. The high group designates soils where the chance that a profitable response from addition of the nutrient is low. The medium grouping is between the high and low classes and designates the transition zone.

This study is designed to gain information regarding the critical level for phosphorus as extracted from the soil; that is, the soil test value below which a profitable response is likely to be obtained. It will furnish information, also, which can be used in the selection of a suitable routine soil test for phosphorus. Likewise, the study will evaluate the readily available phosphorus in the soils studied.

Treatment and Replications

The rates of phosphorus to be applied to each soil are 0, 1/2, 1, and 2 times the rate of the value "X" determined from the phosphorus fixation study conducted in the laboratory. The number of replications to use will be influenced by the space and equipment available for use in the study; usually three replicates are sufficient.

Procedure

1. Weigh the required amount of fine-powdered P fertilizer to give the desired P concentration in 2000 ml of soil as shown in Table 3.

Table 3. Amounts of P fertilizer required for 2000 ml of soil to obtain the desired P concentration

Concentration of P desired in soil following application	mg P per 2 kg soil	Amount of fertilizer to apply to 2000 ml soil	
		as $Ca(H_2PO_4)_2$	as simple superphosphate (20% P_2O_5)
ppm	mg	g	g
0	0	0	0
25	50	0.2	0.6
50	100	0.4	1.2
75	150	0.6	1.8
100	200	0.8	2.4
125	250	1.0	3.0
150	300	1.2	3.6
200	400	1.6	4.8
250	500	2.0	6.0
300	600	2.4	7.2
400	800	3.2	9.6
500	1000	4.0	12.0
600	1200	4.8	14.4
800	1600	6.4	19.2
1000	2000	8.0	24.0

2. Spread each sample of soil in a layer about 1/2 to 1.0 cm thick on a clean sheet of plastic or similar material. Spread the fertilizer uniformly on the soil and mix thoroughly by repeatedly rolling the mixture on the sheet. Take one corner of the sheet and move it toward the opposite corner; then take another corner and move it to the opposite corner. Repeat the operation several times to completely mix the fertilizer with the soil.

3. Place the soil in the weighed container selected for use in the study.

4. Weigh the container and soil; record dry soil weight.

5. Add water to the container to bring the moisture content to <u>within</u> 100 ml of the required volume (refer to Table 2 for the approximation of field moisture capacity). For example: To bring a dry loamy soil to 20% moisture requires adding 400 ml of water to 2000 ml of soil. In this case, add 200 ml of water and 100 ml of the nutrient solution (described in step 6) which will leave a deficit of 100 ml of water.

6. Prepare nutrient watering solution as outlined in Table 4. Add 100 ml of this nutrient solution to each container before seeding and once each week throughout the experiment (do not add entire amount in subsequent applications if there is danger of overwatering).

Table 4. Components of nutrient solution minus phosphorus

Stock Solution	Grams per liter	ml of stock per liter of nutrient solution*
1.0 M KNO_3	101	50
1.0 M $Ca(NO_3)_2 \cdot 4H_2O$	236	50
0.5 M $MgSO_4 \cdot 7H_2O$	123	25
Micronutrient solution 1/		10

1/ Composition of micronutrient solution:

Compound	Grams per liter
H_3BO_3	1.55
$MnCl_2 \cdot 4H_2O$	0.90
$ZnSO_4 \cdot 7H_2O$	0.58
$CuSO_4 \cdot 5H_2O$	0.08
$H_2MoO_4 \cdot H_2O$	0.02

* Add 100 ml per week during the growing period

7. Cover the pots to minimize water loss by evaporation and allow them to stand without further treatment for one week.

8. Seed the pots to millet, sorghum, sudan grass or corn, and cover with damp paper to keep the humidity high on the soil surface. These crop species fulfill most of the requirements for a good test crop because they are well adapted to restricted soil environment and are fast growing, high yielding, and tolerant to a wide range of conditions. Oats and barley are satisfactory crops in cool climates but lodging is often a problem in the

greenhouse. Other crops may be used, including radishes and turnips, but it is advisable to plant a few pots prior to beginning the experiment to determine the suitability of the crop in general for this kind of study under local conditions.

9. During the germination period, the soils are held about 100 ml of water below the approximate field moisture capacity. This will permit a second addition of nutrient solution without overwatering and will also promote a more uniform seed germination. Following germination each pot should be weighed and brought to the approximate field capacity with 100 ml of the minus P nutrient solution plus water. In order to maintain the proper moisture level in the soil during plant growth, the nutrient solution and water should be added regularly. After some experience in watering the growing crop, it is usually only necessary to weigh a few of the pots to calculate the amount of water required and then add this amount to all the pots. The moisture loss will be approximately the same in each pot.

10. Check the pots regularly for water loss and, when the moisture level drops to 60% or 70% of the approximate field capacity, add water or the nutrient solution as required.

11. Observe the progress of the experiment daily and record the appearance of deficiency symptoms, growth characteristics and other pertinent facts.

12. After a four to six-week period, harvest the above-ground portion of the plants and dry at 50° to 60° C. Weigh the material from each treatment. Save the plant tissue for possible future analysis to determine nutrient uptake. For the initial interpretation, however, only the yields are required.

Calculation of Results

1. Compare yields of the treatments receiving the different levels of phosphorus to determine if the "X" value chosen was the rate of phosphorus required for the highest yield in the potted plant study. If treatment "X" has not given the highest yield, note which treatment was superior and redefine "X" on this basis. Future P studies on these soils can be designed on the basis of this information.

2. Calculate the yield from the no-phosphorus treatment as a percentage of the highest yield obtained from the P treatment using the equation:

$$\text{percentage yield} = \frac{\text{yield without phosphorus fertilizer}}{\text{yield with adequate phosphorus fertilizer}} \times 100$$

Interpretation of Data

Plot the percentage yield vs. the soil test value for phosphorus of the samples in the study. Superimpose upon the graph a plastic over-lay divided into quadrants as described by Cate and Nelson (International Soil Testing Technical Bulletin No. 1, 1965).

The soils having a low percentage yield should have a low soil test value and the results should fall in the lower left quadrant. On soils where the percentage yield is high, the soil test value should be high and the plotted data should be in the upper right quadrant. Plotted data that occur in the upper left and lower right quadrants (marked negative) indicate that either the soil test procedure has removed an incorrect amount of the nutrient or that the percentage yield obtained is erroneous. A satisfactory soil testing procedure should place at least 90 percent of the results in the positive quadrants (the lower left and upper right).

A study should be made of the results that fall in the negative quadrants (upper left and lower right) to see if some factor other than the phosphorus has influenced the yields obtained. If no explanation can be found for the poor placement, then the results are due to an inappropriate extractant, soil test errors, or poor techniques utilized in the potted plant study.

The vertical line that separates the quadrants indicates the critical level of phosphorus for the test employed. For example, if this line intersects the soil test value at 12 ppm, this would be the critical level. Soils having less than 12 ppm would be expected to give a profitable response to properly applied phosphate fertilizer but soils with values above 12 ppm are not likely to respond.

A good soil testing procedure will usually have a critical value of more than 5 ppm. A lower value than this allows very little range for errors in sampling or analysis. For example, a procedure with a critical value of 1.5 ppm is so low that a 1 ppm experimental error makes such a value meaningless.

The results obtained in a study in Perú using 15 soils from the coast and high jungle regions are shown in Figure 3. The soils ranged from slightly acid to alkaline in reaction. Both the Olsen and Bray P-1 placed 90 percent or more of the results in the positive quadrants and would be acceptable procedures to use. All of the data obtained with the Olsen procedure fall in the positive quadrants and this should be regarded as the most acceptable of the three procedures tried.

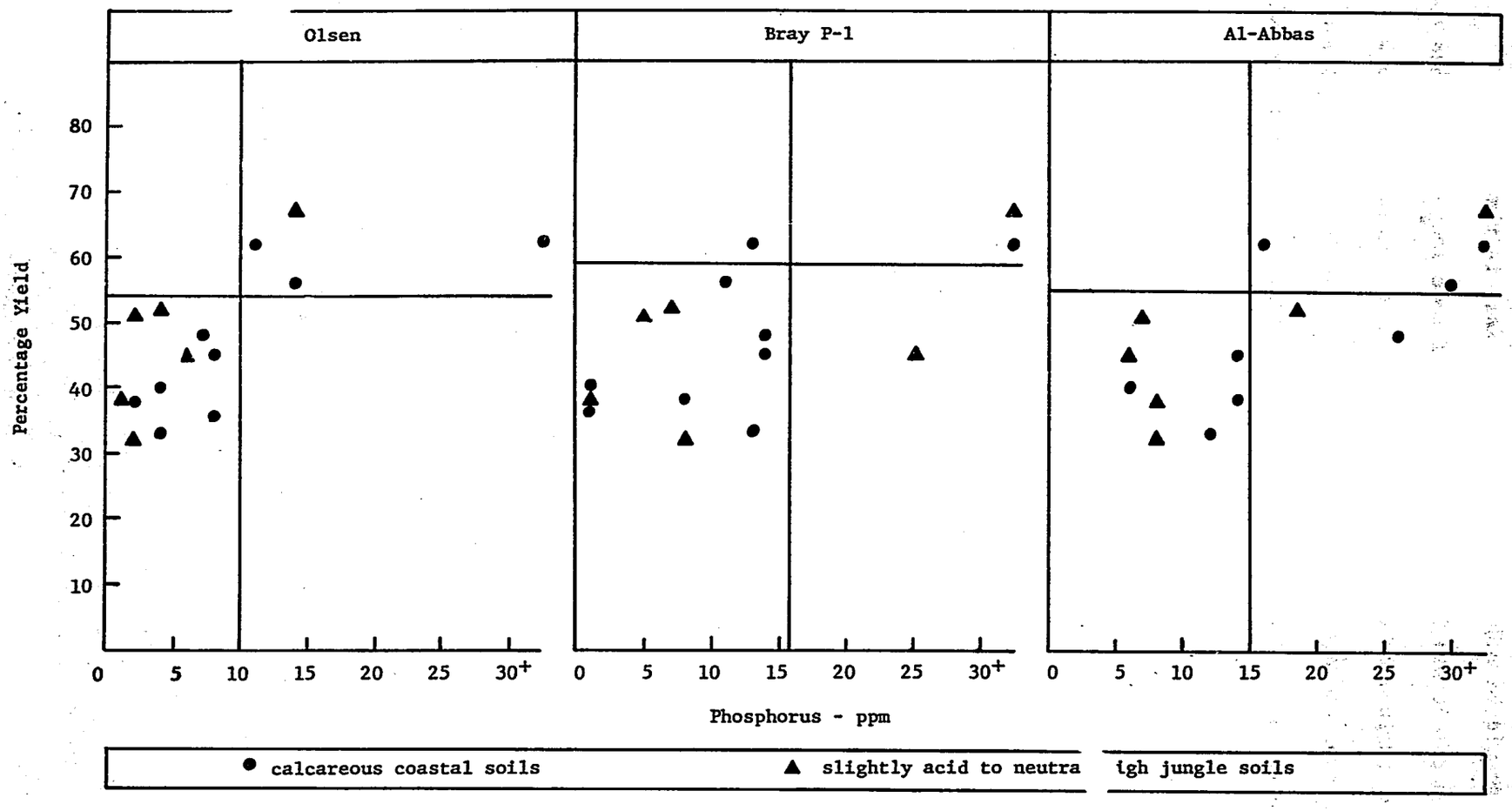

Figure 3. A comparison of percentage yield vs. soil test values for phosphorus by three analytical procedures with 15 soils of Perú. (Data in thesis from research conducted in SIPA by Mueller for Ing. Agrónomo degree, Universidad Agraria, La Molina, Perú, 1966. In Press.)

Readily Available Potassium in Soil

Exchangeable potassium as measured by one normal neutral ammonium acetate is usually considered to be a good guide for readily available potassium in soils. Since exchange properties differ from one soil to another, it is imperative that the results of the soil testing procedure employed be interpreted in terms of plant response to application of potassium to the soil. In addition to evaluating the readily available potassium in the soil, this potted plant study will also aid in the selection of a reliable routine soil testing procedure. The critical level for potassium, that is, the soil test value below which a profitable response is likely to be obtained (Cate and Nelson procedure of interpreting soil test results), can be determined through information gained in the study.

Treatments and Replications

Treatments will include the following concentration of potassium in the soil: 0, 100, 300 ppm K.

At least three replications are suggested.

Procedure

1. Measure an amount of soil appropriate for the size of container to be used. Generally, the amount should not be less than 2000 ml of soil. Weigh soil and pot separately and record weight for future calculations of approximate field moisture capacity and the amount of water or nutrient solution that must be added periodically.

2. Application of phosphorus and potassium to the soil samples.

A. Phosphorus. Select the "X" rate of phosphorus as determined in the P fixation study to apply to the samples. The weight of P to use

either as $Ca(H_2PO_4)_2$ or 20% P_2O_5 superphosphate can be obtained from Table 3 after the "X" value has been determined. The phosphate fertilizer may be mixed throughout the soil mass by rolling the soil and fertilizer on a plastic cloth or paper. Place the soil containing the phosphorus in a weighed pot and add the potassium solution as indicated below.

B. Potassium. Add 200 ml of the appropriate potassium solution to the soil surface to obtain the desired concentration in each pot of 0, 100 or 300 ppm potassium. Refer to Table 5 for directions in the preparation of the 0, 100 or 300 ppm potassium solution. Then apply 100 ml of the nutrient solution minus phosphorus and potassium prepared in accordance with the information presented in Table 4.

Table 5. Preparation of three concentrations of potassium solution

Weight of KCl required to make one liter of Solution A	Solution A Concentration	Concentration of K in soil when 200 ml Solution A is added to 2000 ml soil
g	ppm K	ppm K
0	0	0
1.9	1,000	100
5.7	3,000	300

Table 6. Nutrient solution minus phosphorus and potassium

Stock Solution	Grams per liter	ml of stock solution per liter of nutrient solution*
1.0 M NH_4NO_3	80	25
1.0 M $Ca(NO_3)_2 \cdot 4H_2O$	236	50
0.5 M $MgSO_4 \cdot 7H_2O$	123	25
Micronutrient solution 1/		10

1/ Composition of micronutrient solution:

Compound	Grams per liter
H_3BO_3	1.55
$MnCl_2 \cdot 4H_2O$	0.90
$ZnSO_4 \cdot 7H_2O$	0.58
$CuSO_4 \cdot 5H_2O$	0.08
$H_2MoO_4 \cdot H_2O$	0.02

* Add 100 ml of nutrient solution to each container once each week during the growing period.

3. Allow the treated soil to equilibrate for one week; keep the pots covered to retard evaporation, except in the case of sandy soils where the application of solutions has exceeded field moisture capacity.

4. Plant about 50 seeds of millet, sorghum or sudan grass to each pot. (A planting rate of 50 to 100 seeds should be selected depending upon the size of container used.) These crops are especially adaptable for this study as regrowth is desired after harvest. Cover the pots with moist paper to facilitate rapid and even germination.

5. After the plants are well established (about 7-10 days after seeding), add water or nutrient solution to bring all pots to their approximate field moisture capacity. Check pots regularly for water loss and, when the moisture level drops to about 60% of the approximate field capacity, add water and/or nutrient solution. The 100 ml of the nutrient solution lacking phosphorus and potassium should be applied once each week.

6. Observe the progress of the experiment daily and record the appearance of deficiency symptoms, growth characteristics and other pertinent information.

7. Harvest the above-ground portion of the crop at the end of six weeks and dry at 50° to 60° C. Weigh the material from each treatment.

8. Save all of the pots which received no potassium (0 treatment) and maintain the crop growth for use in the exhaustive cropping study.

Calculation of Results

Calculate the yield from the no-potassium applied treatment as a percentage of the highest yield obtained with potassium in a similar manner as discussed for the P study.

Interpretation of Data

Plot the percentage yield vs. the soil test value for potassium of the soil samples in the study. Interpret the graph in the manner described by Cate and Nelson (International Soil Testing Technical Bulletin No. 1).

The results of the soil tests as compared with percentage yields should fall in the positive quadrants (lower left and upper right) in the same manner as discussed in the phosphorus study. The critical level below which a response should be expected from application of potassium fertilizer is indicated by the vertical line separating the quadrants.

Ammonium Acetate is compared with the extracting solution employed by the Olsen and Bray P-1 procedures on 35 soils in Perú in Figure 4. The possibility of using one extractant for both phosphorus and potassium, as would be possible with either the Olsen or Bray P-1 procedure, greatly enhances the value of the procedure to a soil testing operation. Both the Ammonium Acetate and Bray P-1 extractants placed 91 percent of the samples in the positive quadrants; the Olsen procedure gave almost as good results.

Measuring Potassium Supplying Characteristics of Soils Through Exhaustive Cropping

Only a small portion of the total amount of potassium in soil is in a form that is readily available to a plant. The rate by which the potassium removed from the soil by plant growth is replaced is important in interpreting the results obtained in the readily available procedures. For example, samples of soil placed below the critical level for potassium but which have a percentage yield of more than 90 percent (upper left quadrant of the Cate-Nelson technique) may have a high rate of potassium replacement from the non-readily available to readily available forms. An exhaustive cropping study, where several successive crops are harvested without the addition of potassium fertilizer, may give some important information for evaluating the potassium supplying characteristics of the soil.

Pots not receiving potassium in the readily available potassium study can be used for an exhaustive removal of potassium from the soil. If a crop such as millet, sorghum or sudan grass was used, then a satisfactory regrowth can be obtained simply by watering to the approximate field capacity and applying the necessary nutrients.

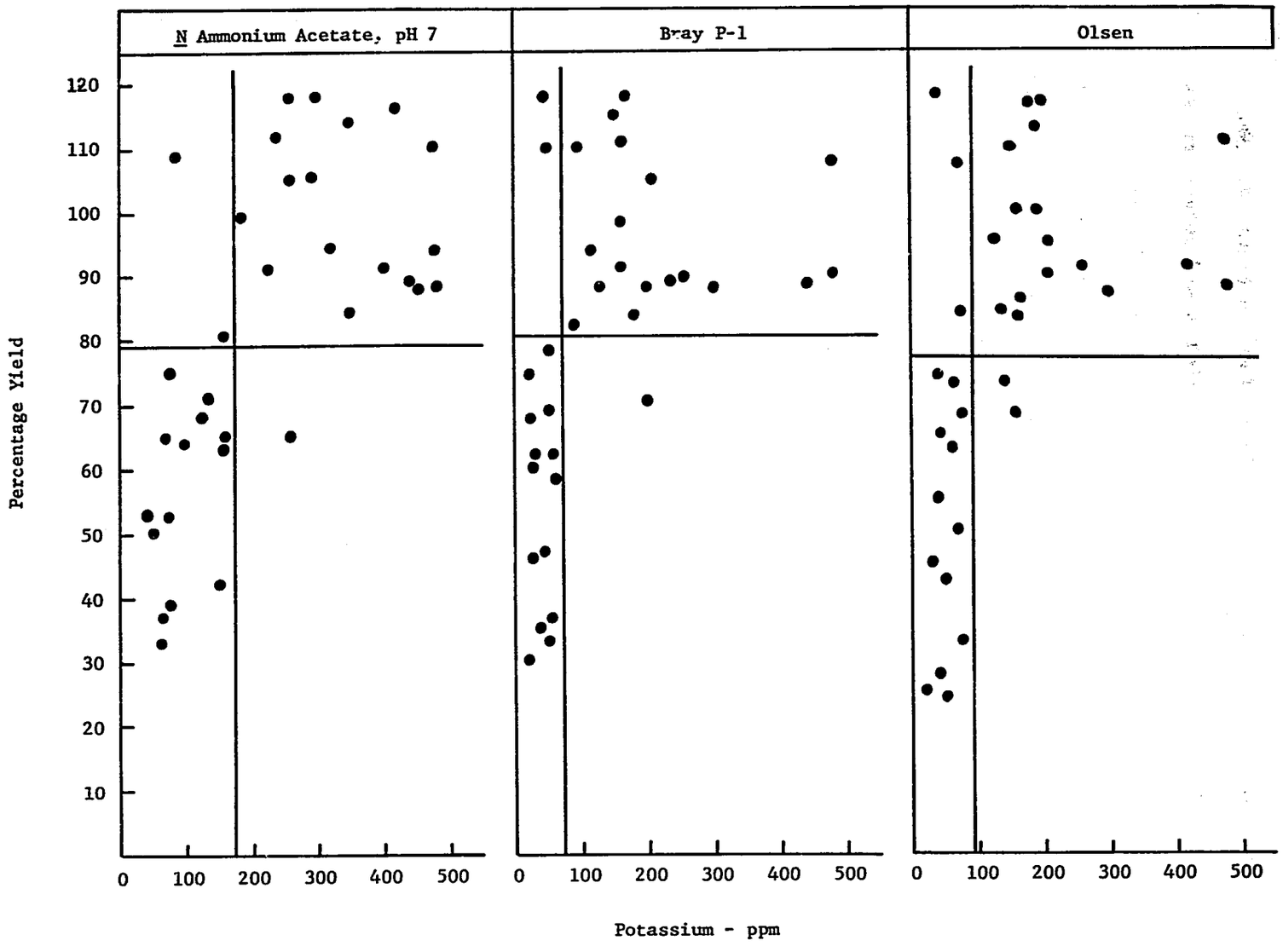

Figure 4. The percentage yield vs. soil test values for potassium as determined by the Olsen and Bray P-1 procedures compared with extracting by neutral ammonium acetate on 35 soils of Perú. (Data in thesis from research conducted by Durán for Ing. Agrónomo degree, Universidad Agraria, La Molina, Perú, 1966.)

Procedure

1. Continue cropping the soils receiving no potassium by adding the appropriate amounts of water. If satisfactory regrowth is not obtained, then the pots must be replanted.

2. Add nutrient watering solution minus phosphorus and potassium at the rate of 100 ml each week until the growth rate begins to decline significantly due to potassium deficiency. Thereafter, add nutrient solution only once each two or three weeks. If more than 3 crops are grown, add additional phosphorus solution at the rate of 100 ppm P (see Table 3). Maintain the moisture levels in the soil to the approximate field moisture capacity by the methods previously discussed.

3. Continue the exhaustive cropping with harvests each six weeks until growth virtually stops.

4. At each harvest dry the tissue and save for total potassium analysis.

5. Total Potassium in Plant Tissue. Extract the potassium directly from the plant tissue without ashing. To accomplish this, place a 0.5 g sample of dried and ground plant tissue in an appropriate extraction bottle or flask. Next, add 100 ml of 2 N NH_4OAc-0.2 N $Mg(OAc)_2$ solution. The extraction solution is left in contact with the tissue for at least one hour with occasional agitation, after which time the suspension is carefully filtered and the potassium determined directly with a flame photometer.

6. Exchangeable K in Soil. The soils included in the study should be analyzed by extraction with N NH_4OAc pH 7.0, both on the original soil and after the last crop.

Calculation of Results

Record the yield of each harvest and the total yield for all harvests.

From the data obtained in the analysis of K in the plant tissue, calculate the total amount of K taken up by the plant in the successive harvests.

Calculate the exchangeable K in the soil samples both before and after cropping. The decrease in exchangeable K is considered to be a measure of exchangeable K taken up by the plant and which has not been replaced from non-exchangeable sources.

The data may be presented in tabular form as shown in Table 7.

Table 7. Exchangeable K in soil before and after exhaustive cropping and potassium uptake from non-exchangeable sources. (After Durán, 1966) 1/

Sample No.	Exchangeable K in Soil		Exchangeable K taken up 2/	Total K taken up by crops 3/	K taken up from non-exchangeable sources 4/	
	Before Cropping	After Cropping				
	ppm	ppm	ppm	ppm	ppm	%
215	77	39	38	896	858	96
304	172	38	132	1466	1334	91
106	162	80	82	512	430	84
211	97	23	74	357	283	79
206	473	56	417	744	327	44
201	230	22	208	320	112	35

1/ Research completed for partial fulfillment of the requirements for the degree of Ing. Agrónomo, Universidad Agraria, La Molina, Perú.

2/ The decrease in exchangeable potassium by soil test is considered as a measure of exchangeable potassium taken up by the plant.

3/ Total K (ppm) taken up in three consecutive crops, determined by (yield) x (percent K in dry tissue), based on mg K per 1000 g soil.

4/ Non-exchangeable K taken up is calculated as the difference between total K taken up and exchangeable K taken up.

Interpretation of Data

The total K taken up by the plants through exhaustive cropping from each soil indicates the capacity factor for the soil K; that is, the potassium supplying power of the soil when subjected to continuous and/or intensive cropping.

Data from six of the soil samples taken from the study of Durán on the potassium supplying power of soils of Perú have been separated into two groups in Table 7. In the first group, soils 215, 304, 106 and 211 have large reserves of non-exchangeable K which became available as the readily available potassium was removed by cropping. Crops growing on samples 201 and 206 had to rely largely on the exchangeable K as the source of potassium. There was very little non-exchangeable reserve for these soils.

The percentage yields in relation to soil test values for readily available K of the data from the six soils that are presented in Table 7 are pinpointed in Figure 5. Samples 215, 304, 106 and 211 are either in the negative quadrant (upper left) or on the border of being in this quadrant. These soils all have large reserves of non-exchangeable K which was readily available to the plants. The low soil test value which measured the exchangeable K in these samples did not give a complete picture of the potassium that would be available to plants.

Sample 206 had a large amount of exchangeable K and this was sufficient for one crop. Sample 201 did not have as large an amount of exchangeable K as sample 206 and, without some additional K from non-exchangeable sources, the crop yield was less than would be expected on most soils with K values above the critical level. Thus, sample 201 fall in the lower right negative quadrant.

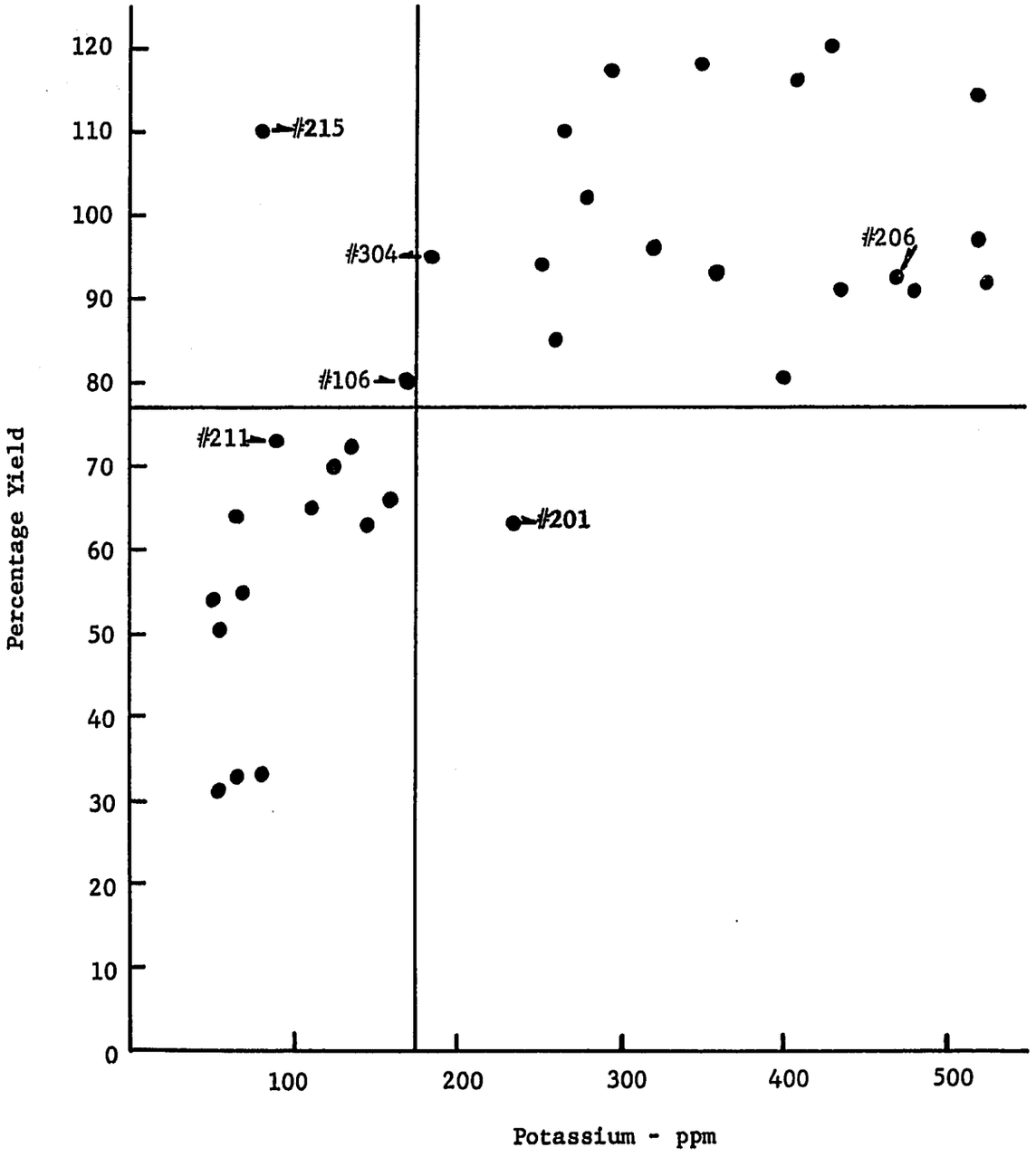

Figure 5. The influence of non-exchangeable K in interpretation studies of soil test results for K vs. percentage yield.

Most available potassium tests are a function of exchangeable K. When more than 90 percent of the soils can be placed in the positive quadrants (Cate and Nelson procedure), then the test should be considered acceptable. The exhaustive cropping study will often show the reason for the placement of some of the soils in the negative quadrants. In regions where a high percentage of the soils have a large release of K from non-exchangeable sources, the critical level will have to be lowered considerably in relation to the condition found in most soils. Likewise, the critical level should be increased in regions where most of the soils have a very low release of the non-exchangeable potassium.

A clay mineral analysis of the soils may also offer considerable useful information on the potassium supplying power of the soils in given regions.

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SOIL TEST INTERPRETATION STUDIES: FIELD TRIALS

INTERNATIONAL SOIL FERTILITY Evaluation & Improvement PROGRAM

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SOIL TEST INTERPRETATION STUDIES: FIELD TRIALS

by

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
UNDERSTANDING FIELD CONDITIONS	2
Important Factors in Field Trials	3
Fertilizer Application in Field Trials	6
Economic Interpretation	7
PREPARING FOR THE EXPERIMENT	8
Test Crop	8
Variety	8
Plant Populations	8
Field Sites	9
Previous Treatments	10
Sampling Soils	11
Number of Trials	11
Farm Cooperators	11
Environmental Observations	13
Nutrients to Test	13
CONDUCTING THE TRIALS	14
Statistical Design	14
Replications	14
Plot Size	14
Plot Shape	15
Treatments	16
Examples of Treatment Schemes	18
Field Techniques	26
Permanent Plot Markers	26
Temporary Plot Markers	27
Marking the Plots for Treatment	29
Maps of Field Trials	29

TABLE OF CONTENTS (continued)

	Page
Management Practices	30
Planting	30
Pest Control	31
Cultivation	31
Irrigation and Other Management Practices	31
Observations During Growing Season	32
Harvesting	32
Harvesting Alleys and Borders	32
Relocating Plots	32
Recording Data	33
MAKING DATA CALCULATIONS	33
Testing the Critical Level	33
Statistical Analysis	36
Data and Information Forms	38
PUBLICIZING THE INFORMATION	38
Signs	38
Plot Signs	38
Field Meetings	42
Photographs	42
Publication	42

SOIL TEST INTERPRETATION STUDIES: FIELD TRIALS

A. H. Hunter and J. W. Fitts

INTRODUCTION

Soil analysis is a means of obtaining information relative to nutrient deficiencies and adverse soil conditions on specific areas of land, especially the individual fields of a farm. The information obtained must first be interpreted into agronomical and biological terms with respect to plant growth in order to determine what conditions can be changed or improved to produce increased crop yields. Interpretation from an economic standpoint to determine what should be done to give the desired economic returns can then be made. Thus, the interpretation of soil analysis is an important and primary part of a soil fertility evaluation program. Waugh and Fitts[1/] outline three steps in obtaining data for interpretation of soil analysis from an agronomic viewpoint. These include: (1) Laboratory data, (2) Potted plant studies, and (3) Field trials. It is stated that, "In obtaining data for soil test interpretation, the philosophy is followed that certain information about the soil should be obtained first in the laboratory and then tested in potted plant studies. Data from the potted plant studies will aid in the selection of a suitable method of analysis and will indicate critical levels of a nutrient in the soil, below which the proper use of

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[1/] Waugh, D. L., and J. W. Fitts. Soil Test Interpretation Studies: Laboratory and Potted Plant. Tech. Bul. No. 3, International Soil Testing Series. 1966.

fertilizer containing that element should be profitable. The final test of these established critical levels must be made with carefully conducted field trials."

Procedures were outlined by Waugh and Fitts for obtaining soil samples and for conducting laboratory and potted plant studies for agronomic interpretation of soil analysis results. Conducting field trials is the next step in the correlation studies. The objectives of this bulletin are:

1. To outline some field procedures and suggest treatments that can be used in field experiments to obtain soil analysis interpretation data for confirming or adjusting the previously determined nutrient element "critical level."
2. To present procedures for selecting field sites for conducting trials.
3. To discuss techniques for conducting field trials and for summarizing and publicizing the data.

UNDERSTANDING FIELD CONDITIONS

Plant growth under field conditions is one of the most complex physical, biological, and chemical systems known to man. Fitts[2/] has pointed out that crop yield is a function of soil, crop, climate, and management. Each of these factors is a complex system which

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[2/] Fitts, J. W. Research Plus Extension = Bigger Farm Profits. Plant Food Review. 1959.

acts on and reacts with one another. Crop yield under field conditions, then, is dependent on the interaction of the variable of each of the four factors; and the maximum yield of which a plant is genetically capable can be obtained only when every other factor becomes non-limiting. Since many of the variables are difficult or impossible to precisely control or measure, field studies are difficult to conduct with a high degree of accuracy. It is for this reason that the procedure of conducting laboratory and potted plant studies prior to field trials is recommended. However, most crops are grown in fields; and recommended practices for obtaining field production must be based on field conditions. Therefore, it is necessary that field trials be conducted to test the information gained in the laboratory and from potted plant studies.

Important Factors in Field Trials

Field experiments are time consuming and expensive to conduct. In order to obtain the maximum results from the effort and cost invested in field experiments, certain pertinent facts should be considered.

1. Planning and outlining the studies is important, but conducting the trials is even more important. The person in charge of the field experiments should give careful supervision to all phases of field operations in order to assure accurate data. The field operations should not be turned over to an assistant who may have

little training, experience, or appreciation for the manner in which the trials are conducted. Poorly conducted trials can only result in poor data, and poor data is likely to be worse than none at all.

2. The more important problems affecting the agricultural production in an area should receive priority. Trials should be conducted first on the more extensive and important agricultural soil types. Nevertheless, problems which affect only a small portion of an area should not be ignored. From the standpoint of the individual, it is equally important for one farmer with uncommon soils problems to know the answers as it is for another farmer with common soils problems.
3. As much information as possible relative to soil conditions should be obtained. This includes a knowledge of the soil type which will help in extrapolating the results to other regions.
4. Crop varieties differ in their ability to respond to fertilizers.
5. The time of planting may be very important because of climatic conditions. Crops planted at the wrong time may give an unusually low yield and obtain little benefit from the fertilizers applied.
6. If irrigation is to be used in conducting the experiment, careful planning and complete arrangements for the

application of water should be made prior to initiating the experiment. Poor distribution or late application of water will introduce large variables and may negate the benefits of the treatments.

7. Pest control is essential. Weeds respond to fertilizer and may actually reduce crop yields. Insect and disease damage may be greater on fertilized plots, especially if the crop growing on the fertilized plots is a few days advanced in growth. A heavy infestation of nematodes which will limit crop growth should be avoided or the area treated to control them.

8. Other adverse soil conditions should be avoided or corrected when testing critical levels of nutrient elements. Acid soils should be limed appropriately before initiating a trial. Likewise, saline or alkaline conditions should be corrected or avoided, etc.

9. An examination should be made of the entire soil profile to ascertain probable root distribution. Plow pans, clay pans, or other barriers to roots may greatly influence the results obtained in the field study. A high water table or poor physical conditions in general may ruin an experiment also. The lower horizons should be sampled and tested for nutrient availability. For example, a crop may not respond

to added phosphorus or potassium even though the plow layer is below the critical level if the lower horizons are high in the element.

Any adverse condition may invalidate the field experimental data for the purposes set forth in this paper. It should be remembered that if the results from a field experiment do not coincide or relate with those of the laboratory and greenhouse, it does not necessarily indicate that either is wrong. This situation may occur as a result of unrecognized or uncontrolled variables frequently associated with the field experiment. An attempt to reconcile the results by further investigation is a more logical approach than to conclude that the results from the different approaches are not related.

Fertilizer Application in Field Trials

Not all of a nutrient element that is applied in a fertilizer is taken up by the crop being grown. Some may be absorbed by weeds, some lost by leaching or volatilization, and some by reaction with the soil to become less available. Fertilizer placement, time, rate and method of application are all very important in the efficient use of fertilizers. It is not the purpose of this bulletin to outline procedures to obtain data on these problems. Such studies should be conducted in addition to correlation studies. However, correlation studies as outlined in this bulletin should be made prior to other field trials since such studies should be conducted

on soils which are below the critical level in nutrient content of the element of interest. Conducting studies relative to placement, time, rate and method of application of a fertilizer element on soils which are not likely to give a plant growth or yield response by the addition of that element is a waste of time and effort and is likely to lead to incorrect conclusions.

Economic Interpretation

The purpose of soil analysis is to obtain information which can be used in making a decision on the use of fertilizer and other soil amendments. A farmer is always faced with the question of where to invest his limited resources to obtain the greatest return. Interpreting soil test information in terms of economic return is another very important phase of soil fertility evaluation. Of course, the accuracy of the economic interpretation is dependent upon the data available. Although some information of economic value will be obtained in the procedures outlined in this bulletin, these studies may be incomplete for economic purposes.

Additional studies for economic interpretation should be made using the information obtained in these correlation studies. With this information, the soils can be separated into two groups: (1) those below the critical level and can therefore be expected to give large yield responses to the addition of the nutrient element, and (2) those which are above the critical level and can be expected to give relatively small responses to the addition of the element.

PREPARING FOR THE EXPERIMENT

Test Crop

Information relative to the critical level of nutrient elements for the major crops grown in an area will be desirable. For the purpose of testing the critical level, usually an annual crop that is known to be responsive to the element in question is best. Thus, initially it may be desirable to use the same crop as used in the potted plant study, or one similar to it in nutrient requirements and growth habits. Wheat, corn, sorghum, and barley are widely grown and are easy to use in field trials. Since an economic interpretation is not the objective of this phase of testing, the residual benefit of the fertilizer is not a major factor.

Variety

Crop varieties may vary greatly in their ability to utilize the fertilizer applied. It is important to use a variety which has been proven to be high yielding in the area, to utilize high fertility levels without lodging, etc., to be resistant to the diseases of the area, and to be adaptable to the environmental conditions. Varieties adapted to low fertility conditions will often not respond to increased fertility and, therefore, are not suited for use in these experiments.

Plant Populations

Only a general statement concerning plant populations can be made here since the optimum plant population depends on a number

of factors. Some varieties of corn, for instance, are sensitive to high population while others are tolerant or adaptive. In field experiments, plant population should be sufficiently high to take advantage of the best growing conditions in the area when the fertility status of the soil is high. Although the amount of moisture available for crop growth is a factor to be considered, research has shown that yields of well fertilized corn do not fall off very sharply when plant population is above optimum even in dry years.

Field Sites

In conducting the potted plant studies leading to the field trials, no doubt the soil samples should be taken from the major cultivated soil types in the region. It is desirable, of course, to conduct the field trials on the same fields from which samples were taken for the potted plant studies. However, the fields selected should meet the following conditions:

1. The area should be uniform and consist of only one soil type.
2. Soil type should be one commonly cultivated within the region.
3. The site selected should not be marred by cross-drainage ways, plow furrows, old fence rows, or any other such conditions which will influence the crop yield.

4. If irrigated, the water distribution for each row and plot should be the same.

5. The site should be sufficiently large to have a border area of the same crop around it for a distance of about 20 meters. In other words, the plots should not extend to the edge of the field.

6. A large number of fields representing a wide range of nutrient levels for a given element are necessary for establishing a critical level. However, the number needed can be reduced by selecting a majority of the fields which according to soil analysis are close to (above and below) the critical level that was established by the potted plant studies.

Previous Treatments

The effect of previous treatments may be considerable, especially if the trial is located on an experiment station where plot studies have been conducted for several years. Although good management is usually given to experiments conducted at experiment stations, past cropping patterns on small plots often introduce a variable that is difficult to overcome. Care should be taken to be sure that any soil amendments in the form of lime or fertilizer that have been previously applied are uniformly mixed with the soil of the entire area on which this study will be conducted.

Sampling Soils

Even though a field may have been sampled for the potted plant study, composite samples should be taken from each replication before the treatments are established. This is necessary in order to obtain information about the variability of the entire site. If much variability is found, then another site should be selected for the trial.

Number of Trials

For the purpose of testing and adjusting critical levels according to the field environmental conditions, a relatively large number of field trials are needed. Therefore, a relatively simple experiment is suggested in order that more trials can be conducted.

All field trials require considerable supervision and work. Thus, the number of trials undertaken should not exceed the capacity of the staff and equipment to properly conduct them. Poorly conducted trials will result in erroneous data and incorrect conclusions.

Farm Cooperators

In order to find the desired conditions for obtaining correlation data to test soil nutrient critical levels, it is necessary to locate most of the trials on farmer's fields.

Of paramount importance in conducting the field trials is the interest and cooperation that can be obtained from the farmer upon whose land the trial is to be conducted. No matter how well an

investigator may plan or conduct a field trial, failure will result if the farmer interferes with or neglects the plots. For example; if he applies other materials (including fertilizers or pesticides); if he permits insect, weed or disease damage, or plant injury from cultural practices; the data is not likely to be useful. At best, it will have a high experimental error. The purpose of the trial should be explained to the farmer; and if his interest is indicative of a good cooperator, then the details of conducting the experiment should be carefully reviewed with him. An outline of the plots should be given to the farmer-cooperator along with a list of duties that he will be expected to perform.

Often the field trial can become a community or village project if an explanation is given to the community of the objectives of the trial and what is expected. Usually the site is selected on the land of a community leader if the soil conditions desired are available. Recognition of the cooperator is important. In addition to influencing the collection of good data, the cooperative spirit developed here can be utilized later in educational and promotional programs.

The farmer should be furnished materials and instructions for keeping notes on any observations that he may make during the course of the experiment. He should also be given instructions on how to contact the person responsible for the trials in case he needs to seek advice or to report unusual conditions.

Environmental Observations

Climatic factors or other environmental conditions may greatly influence the results of the field trial. For example, a prolonged dry or wet period may have a marked effect upon the crop yield and may influence the response to fertilizer. Notes should be made of such conditions; and if the site cannot be visited frequently by the investigator, forms should be prepared to assist the cooperator in noting the conditions.

Small inexpensive rain gauges may be installed on some farms and the farmer asked to keep a record of the rainfall pattern. Usually the cooperator is most willing to do this as it furnishes information of interest to him.

Nutrients to Test

The principal objective of the field trials described in this bulletin is to test the critical levels of the various nutrient elements. In most areas, the initial interest will be in the primary nutrient elements (nitrogen, phosphorus, and potassium) since these are most frequently in short supply and since reliable analytical procedures are available for phosphorus and potassium. The procedures outlined, however, may be used for the other essential elements for which correlation studies need to be conducted. The examples presented here, however, will involve only the primary nutrients.

CONDUCTING THE TRIALS

The primary objective of the field trials as outlined in this bulletin is to test the critical level for an element as previously determined by laboratory and potted plant studies. The trials should be so designed that a statistical analysis can be made of the results. Of course, all possible precautions should be taken to assure good data.

Statistical Design

As a rule, the best statistical design is the simplest one which will accomplish the purpose. A randomized complete block design will give adequate precision for testing the critical levels.

Replications

In order to measure variability and to have an estimate of experimental error, replication of treatments is a necessity. For field plots, the American Society of Agronomy Standards suggests three to six replications; and this should be sufficient for these studies.

Plot Size

The size of a field plot influences the accuracy. As plot size changes, there are two opposite tendencies that affect the experimental error. Generally, as the plot size increases there is a decrease in experimental variability because of increased precision in the individual plot yield. However, at the same time

there is an increase in variability within the block or replication which occurs due to the increase in heterogeneity of the soil. For one-season trials on annual crops, the variation usually is reduced with increasing plot size until plot size is increased to 1/100 hectare; and then very little, if any, further decrease in variation is obtained by increasing the size. A plot size of 1/100 hectare is suitable for most crops and working conditions, but conditions may make larger or smaller plots desirable.

Other factors to be considered in choosing the plot size are: the kind of crop, the area available, the duration of the experiment (more than one crop on some areas), the cost of treatment, and the funds available, as well as the type of machinery to be used, etc. Where possible, it is recommended that standard farm machinery be used for planting and cultivating.

Plot Shape

Statistical studies have indicated that long narrow plots with the long dimensions oriented in the direction of the greatest soil variation give the most precision. This shape of plot is usually more suitable for farm machinery.

The removal of some border area at the head of the plots to provide alleys for working and viewing the plots is usually desirable. Therefore, space should be provided for this.

It is desirable that the plots be made a fractional part of a hectare of such size as to avoid computational errors. For example;

if corn is planted in rows 90 cm apart, using a four row planter, the length of row for a plot 4 rows wide and 1/100 hectare in area is calculated as follows:

100 square meters/3.6 meters = 27.78 meters for length of plot.

In this case, the outside 2 rows of each plot can be guard rows, and the 2 inside rows can be harvested for yield data. The harvested area would then be 1/200 hectare.

Treatments

The simplest form of field trial which will furnish data for testing the critical level is one which has two treatments. One treatment will provide all elements in adequate amounts to obtain maximum yield response, and the other will provide adequate amounts of all elements except the one of interest for which none of this element will be added.

However, simplicity can still be maintained with a few additional well chosen treatments included at each location which will provide more precision and total information.

These additional treatments will add very little effort and cost to that required for the simplest form of trial and will provide the following information:

1. A percentage yield point for plotting a Cate-Nelson[3/] graph

[3/] Cate, R. B., Jr., and L. A. Nelson. A Rapid Method for Correlation of Soil Test Analyses with Plant Response Data. Tech. Bul. No. 1, International Soil Testing Series. 1965.

will be obtained for each of the three primary elements (N, P, and K) instead of only one.

2. Since the precise quantity of element required for obtaining maximum response is not usually known, the additional treatments will provide a response curve to indicate whether maximum yield is reached. If maximum yield is not obtained, then the calculated percentage yield point will be in error and could lead to an erroneous conclusion.

3. The response curves may also provide data for economic interpretations.

Therefore, it is suggested that relatively simple experiments be conducted in which the treatments are spaced around a base rate. The fertilizer rates of all the elements and amendments applied at the base rate are those considered to be "optimum" and economically feasible for one season and can be determined by using information from:

1. Soil analysis
2. Existing experimental data
3. Other soil conditions including soil type
4. Crop to be grown
5. Climatic conditions (including irrigation)
6. Economic considerations
7. Management practices, etc.

From the base rate, variable rates are assigned in turn to each of the three elements to be varied while holding all other additions constant at the base rate. The variable rates will be 0, 1/2 base rate, and 1½ base rate. (Under circumstances where there may be considerable uncertainty as to whether the base rate may be adequate for maximum response, then a 2 base rate may be included or substituted for the 1½ base rate.) A treatment, N_0-P_0-K_0, is included as a means of indicating the native fertility status of the soil with no N-P-K added.

Examples of Treatment Schemes

The treatments for a specific experimental site, of course, will depend upon the soil analysis and the specific information desired. Four examples are presented to illustrate how the treatments may be arranged. These apply to the following situations:

Example 1

For soils which are below the critical level for both phosphorus and potassium with a response anticipated from nitrogen.

Example 2

For soils that are below the critical level for phosphorus but above for potassium with a response anticipated from nitrogen.

Example 3

For soils that are below the critical level for potassium

but above for phosphorus with a response anticipated from nitrogen.

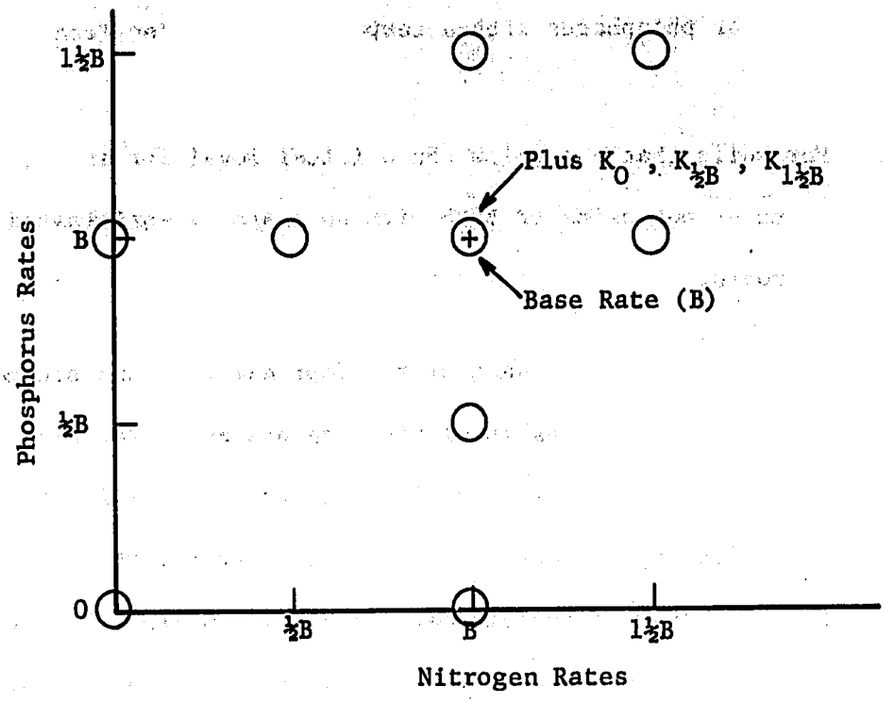
Example 4

For soils that are below the critical level for either phosphorus or potassium or both with no response anticipated from nitrogen.

Suggested treatments for each of the four examples and schematic diagrams to show the relationship of the elements and rates are presented in Figure 1 through Figure 4. The basic scheme for the variable treatments is presented in Figure 1. A treatment of $N_{1\frac{1}{2}B}$ $P_{1\frac{1}{2}B}$ $K_{1\frac{1}{2}B}$ is included to determine if increased yield results from increasing all three element rates above the base rate. This will serve to indicate whether the base rates are well chosen.

In example 2, where phosphorus in the soil is below the critical level but potassium is above, the $K_{\frac{1}{2}B}$ and $K_{1\frac{1}{2}B}$ treatments are eliminated. Thus a response curve for K will not be obtained. However, the base rate treatment will receive a potassium application K_B equal to the rate which will be applied if a yield response is expected. This is intended to insure that K is not limiting and will permit observance of a K response if there is such a response.

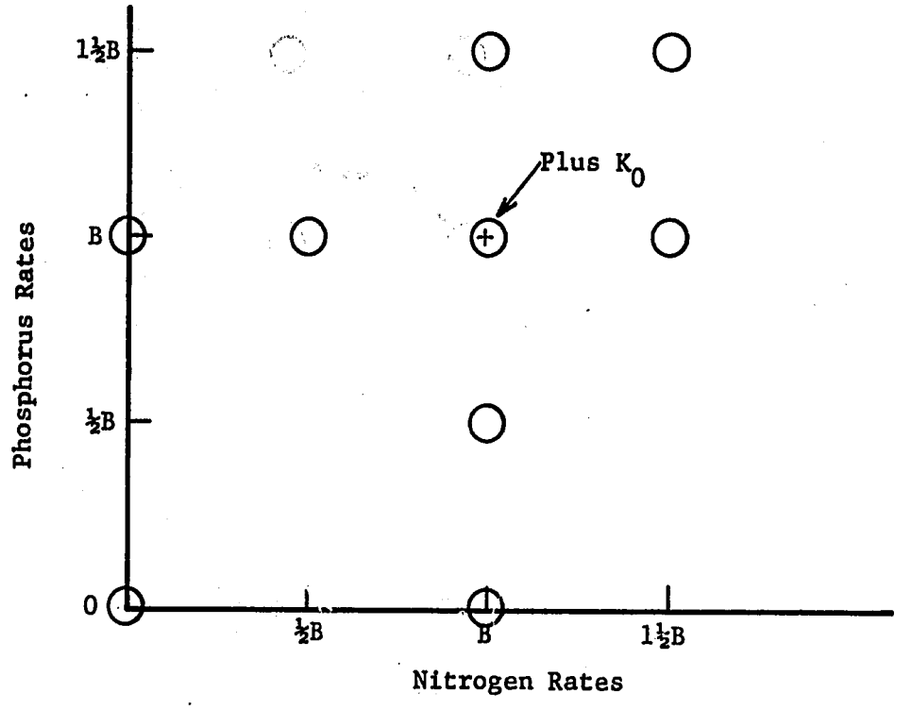
Example 3 is very similar to example 2 except the emphasis is upon potassium rather than phosphorus, since the soils involved will be below the critical level for potassium and above for phosphorus. Of course, the explanations given for example 2 will also apply for example 3.



Treatments:

1. $N_0\ P_0\ K_0$
2. $N_0\ P_B\ K_B$
3. $N_{½B}\ P_B\ K_B$
4. $N_B\ P_B\ K_B$
5. $N_{1½B}\ P_B\ K_B$
6. $N_B\ P_0\ K_B$
7. $N_B\ P_{½B}\ K_B$
8. $N_B\ P_{1½B}\ K_B$
9. $N_B\ P_B\ K_0$
10. $N_B\ P_B\ K_{½B}$
11. $N_B\ P_B\ K_{1½B}$
12. $N_{1½B}\ P_{1½B}\ K_{1½B}$

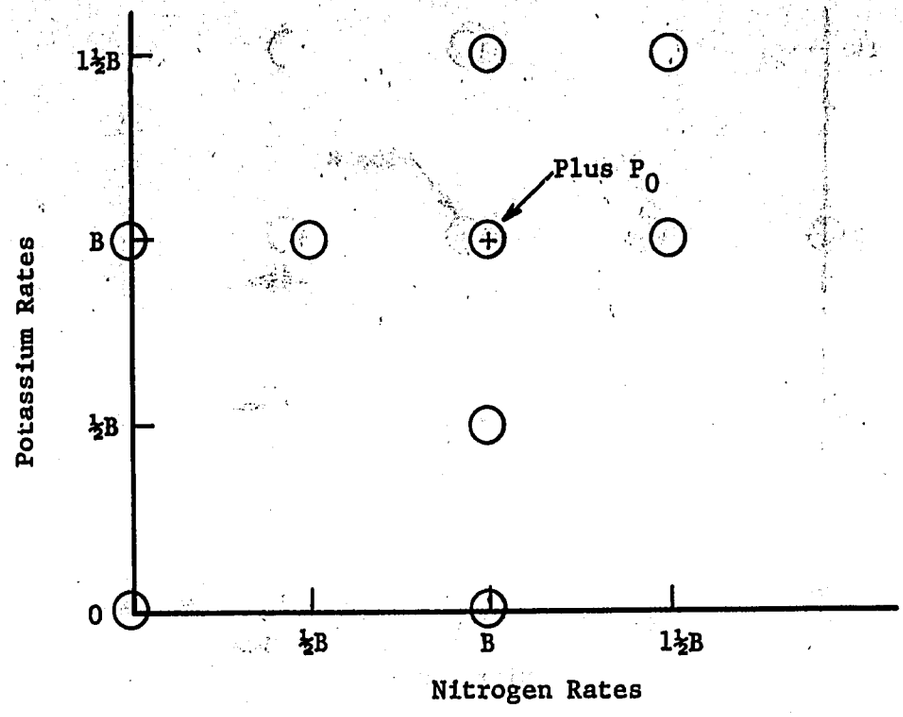
FIGURE 1. Basic scheme for treatment combination to be used for soils which are below the critical level for both phosphorus and potassium and a response is anticipated from nitrogen (Example 1).



Treatments:

1. $N_0\ P_0\ K_0$
2. $N_0\ P_B\ K_B$
3. $N_{\frac{1}{2}B}\ P_B\ K_B$
4. $N_B\ P_B\ K_B$
5. $N_{1\frac{1}{2}B}\ P_B\ K_B$
6. $N_B\ P_0\ K_B$
7. $N_B\ P_{\frac{1}{2}B}\ K_B$
8. $N_B\ P_{1\frac{1}{2}B}\ K_B$
9. $N_{1\frac{1}{2}B}\ P_{1\frac{1}{2}B}\ K_{1\frac{1}{2}B}$
10. $N_B\ P_B\ K_0$

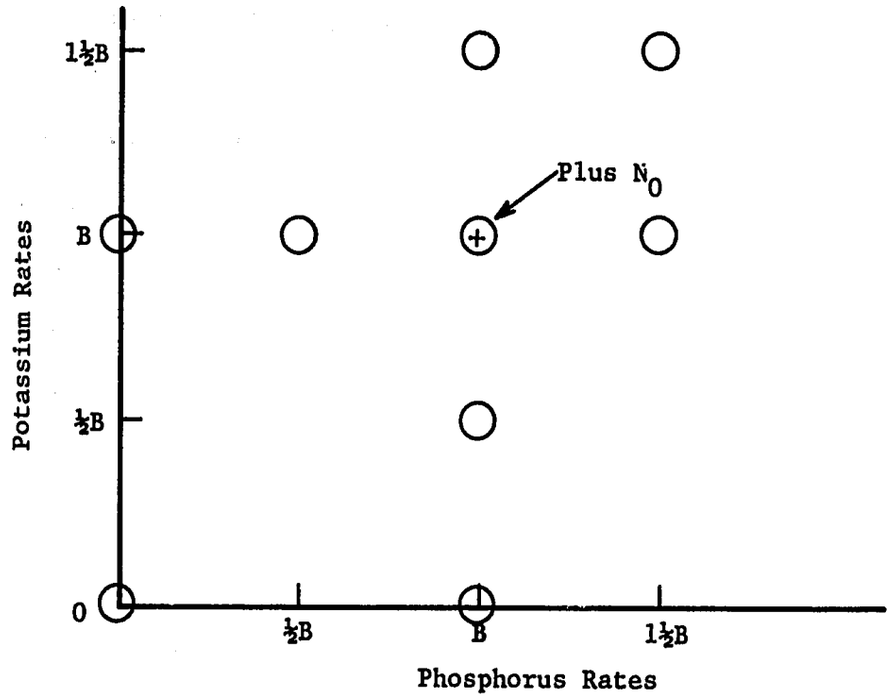
FIGURE 2. Treatment combination to be used for soils that are below the critical level for phosphorus but above for potassium and a response is anticipated from nitrogen (Example 2).



Treatments:

1. $N_0\ P_0\ K_0$
2. $N_0\ P_B\ K_B$
3. $N_{\frac{1}{2}B}\ P_B\ K_B$
4. $N_B\ P_B\ K_B$
5. $N_{1\frac{1}{2}B}\ P_B\ K_B$
6. $N_B\ P_B\ K_0$
7. $N_B\ P_B\ K_{\frac{1}{2}B}$
8. $N_B\ P_B\ K_{1\frac{1}{2}B}$
9. $N_{1\frac{1}{2}B}\ P_{1\frac{1}{2}B}\ K_{1\frac{1}{2}B}$
10. $N_B\ P_0\ K_B$

FIGURE 3. Treatment combination to be used for soils that are below the critical level for potassium but above for phosphorus and a response is anticipated from nitrogen (Example 3).



Treatments:

1. N_0 P_0 K_0
2. N_B P_0 K_B
3. N_B $P_{\frac{1}{2}B}$ K_B
4. N_B P_B K_B
5. N_B $P_{1\frac{1}{2}B}$ K_B
6. N_B P_B K_0
7. N_B P_B $K_{\frac{1}{2}B}$
8. N_B P_B $K_{1\frac{1}{2}B}$
9. $N_{1\frac{1}{2}B}$ $P_{1\frac{1}{2}B}$ $K_{1\frac{1}{2}B}$
10. N_0 P_B K_B

FIGURE 4. Treatment combination to be used for soils that are below the critical level for either phosphorus or potassium or both but no response is anticipated from nitrogen (Example 4).

In example 4, the $N_{\frac{1}{2}B}$ and $N_{1\frac{1}{2}B}$ treatments were eliminated, but an N_0 P_B K_B is included.

As mentioned earlier, the rates of N, P, and K are based (where possible) on information already available for the experimental area. The P and K will normally be applied in a band at planting time. Where information as to rates is lacking or scarce, the following suggested rates for phosphorus or potassium application as shown in Table 1 might be used.

TABLE 1. Suggested rates for phosphorus and for potassium to be applied in bands at planting when information for choice of base rate is insufficient.

		P_2O_5 OR K_2O (kg/ha)			
		P_0 OR K_0	$P_{\frac{1}{2}B}$ OR $K_{\frac{1}{2}B}$	P_B OR K_B	$P_{1\frac{1}{2}B}$ OR $K_{1\frac{1}{2}B}$
Low Value Crops	(1)	0	12.5	25	37.5
	(2)	0	25	50	75
Medium Value Crops	(1)	0	25	50	75
	(2)	0	50	100	150
High Value Crops	(1)	0	50	100	150
	(2)	0	100	200	300

(1) Soils which exhibit little or no phosphorus or potassium fixation.
(2) Soils which exhibit phosphorus or potassium fixation.

Where studies have shown that the soil has a large capacity to tie up or fix either phosphorus or potassium, then the following additional treatment combinations would be desirable:

(1) N_B P_X K_B on soils which tie up or fix phosphorus

(2) N_B P_B K_X on soils which tie up or fix potassium

(3) N_B P_X K_X on soils which tie up or fix both phosphorus and potassium.

In these treatments, the "X" rate of element refers to that rate which was determined by laboratory and greenhouse studies as being the amount of element necessary to overcome the fixing capacity of the soil throughout the plow layer and to raise the soil analysis level of the element to well above the critical level. In these treatments, all of P and/or K should be broadcast and mixed with the plow layer of soil. An adequate level of nutrients throughout the plow zone, rather than in a localized band, usually provides a better environment to take advantage of other factors which affect plant growth.

Depending on the crop, the fixation capacity, etc., the "X" rate may or may not be economically feasible for one cropping season.

It is suggested that on those soils where the "X" rate of an element does give maximum response, but may or may not be most economical, that a long term experiment be conducted. In these experiments, the "X" rate would be applied only the first year. In

subsequent cropping seasons, no additional "X" rate element is needed, but the base rate of the other elements will continue to be added as will the other treatments in the same plot locations. The experiment shall continue until the total element added in the base rate treatment equals the amount added as "X" rate the first year. These data will not only provide for a proper percentage yield to be calculated the first year, but will permit decisions concerning methods and rates of application on soils which fix the element.

Field Techniques

Much effort may be expended in outlining a satisfactory experiment to obtain the information desired; but unless the field techniques are good, the results are likely to be erroneous. The field techniques include: site selection, sampling soils before initiating the experiment, location of boundaries, preparing the seed bed, planting, treatment application, and control of pests and weeds, etc. One of the most important activities is keeping a complete set of notes with dates of each observation and operation carefully recorded.

Permanent Plot Markers

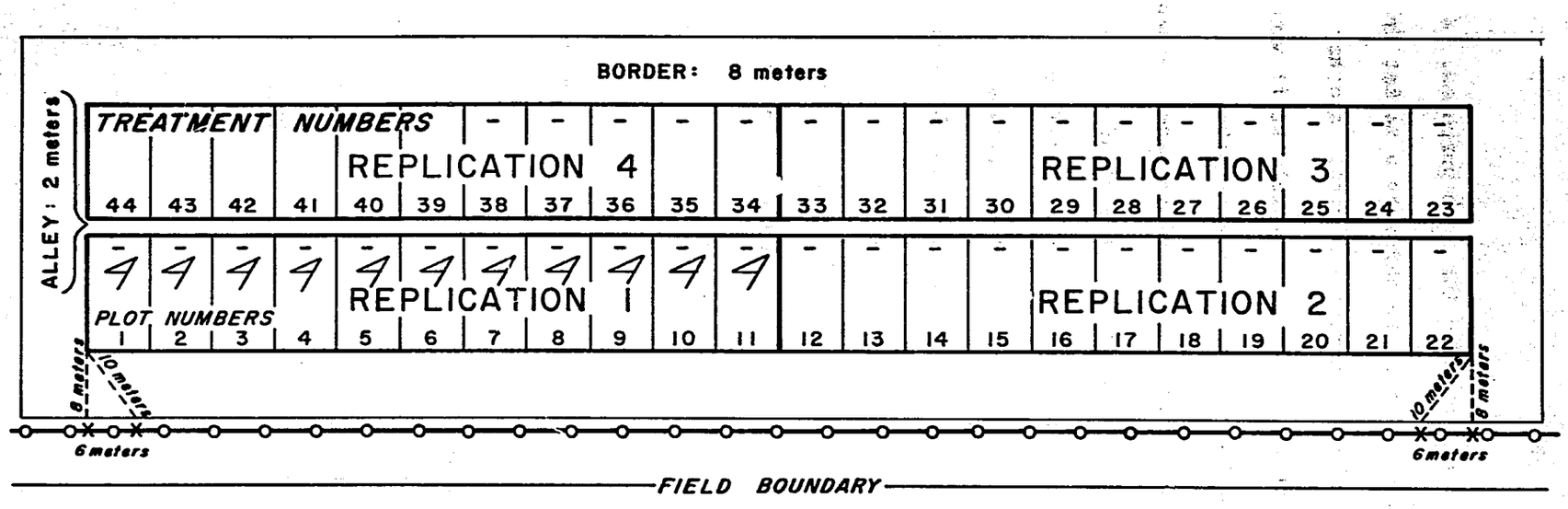
After the site has been selected, the corners of the blocks should be located in reference to some permanent marker or at least a marker that will remain until the experiment is completed.

A fence on the edge of the field may be used for such purposes. A nail can be driven into a post, or a tree, to serve as a marker from which to measure to the corner of experimental site. Another technique is to tightly wrap a short piece of moderately stiff wire around the strand of wire in the fence. If a fence or other markers are not present around the field, then semi-permanent stakes can be driven into the ground around the edge of the field. These should be driven almost flush with the ground to avoid difficulty with farm machinery and removal for firewood or other purposes.

The edge of the plots or the corner of the block can be located by triangulation. In a right triangle, the square of the hypotenuse is equal to the sum of the squares of the other two sides. An example of locating plot corners by triangulation from permanent markers is shown in Figure 5, a map of an experiment.

Temporary Plot Markers

At the time that treatments are established and during harvest, it is necessary to locate the corner of each plot. Small stakes can be used for this purpose and removed after each operation. The corner stakes of the blocks may be left, but they may be destroyed or moved by cultural practices during the growing season. Thus, they should be remeasured from the permanent markers for each operation.



X = PERMANENT MARKERS
4 = COLOR STAKES AND NUMBERS FOR TREATMENT IDENTIFICATION
—o— = FENCE

FIGURE 5.

Marking the Plots for Treatment

After the plots are laid out, it is desirable to check each plot with respect to the treatment it will receive against the experimental outline. An easy way to do this is to assign a color or a combination of colors to each treatment. Of course, the plots will also be numbered. The N_0 P_0 K_0 treatment may be white, the N_0 P_B K_B may be red, etc. A combination of colors as red and black can be assigned treatments, too, if need be. Wire stakes with plastic flags or painted wooden stakes are good for this purpose. A plot number can be assigned to each stake before going to the field and the stakes strung on a wire. This permits a rapid placement of the stakes in the plots. Then it is possible to stand on one edge of the experiment and check all plot treatments against an outline. When establishing the treatments, they should be checked against the color to avoid errors in application.

The same procedure may be followed during harvest. As each plot is harvested, the flag is brought to the weighing center with the sample. This serves as an added precaution against error of mixing samples or of harvesting the wrong plot.

Maps of Field Trials

A complete field plan map and notes should be prepared for each experimental site. An example of such a map is shown in Figure 5. Several copies should be made of each map--some for field

use and the office files, others for cooperators, extension agents, et al. The notes will include date of planting, soil conditions (including moisture), and any special physical conditions, etc.

Management Practices

Seedbed preparation should be done at a time and in such a manner as to maintain or improve soil physical conditions and prevent loss of needed moisture. As a rule, the seedbed should be worked as little as possible in its preparation. The following goals should be achieved in good seedbed preparation:

1. Provide a suitable environment for seeds to germinate and for roots to grow.
2. Adjust to the planting and cultivating tools that are available.
3. Control weeds by chemicals or tillage when necessary.
4. Preserve or improve soil physical conditions.
5. Prepare soil so as to allow water infiltration readily.
6. Prevent wind and water erosion.

Planting

Soil moisture and soil temperature are important factors to be considered in planting. They should be adequate to allow rapid germination of properly placed seed. Where seeds germinate under adverse conditions, the plants are less vigorous and may not realize their full yield potential.

In most areas, there is an optimum date of planting. Since a number of experiments will usually be planted, the investigator should arrange his schedule so as to start planting a short while ahead of and finish a short while after the optimum date.

Pest Control

It is especially important that all types of pests (i. e., weeds, insects, and diseases) be controlled in the experimental plots so that these do not become the limiting factors in controlling yield. If pests become the limiting factor, then the importance of the effect of the variable being studied is either masked or lost. In view of this, steps should be taken for pest control within the experimental site even if the farmer-cooperator does not control them on the rest of the field.

Cultivation

Cultivation can usually be done by the farmer at the same time he is doing the rest of the field. The complete experimental site should be cultivated in the same manner and at the same time.

Irrigation and Other Management Practices

If irrigation is done, care should be taken to provide equal water application to the entire experimental site.

The farmer should be instructed that when any management practice is performed on the experimental site, it must be performed in an equal manner over the whole site.

Observations During Growing Season

The experiment should be observed several times during the growing season and notes taken relative to differences that are apparent. Likewise, any unusual condition should be recorded.

Tissue analysis and plant sampling may be desirable if some unusual conditions are observed or if additional information is desired Of course, the plant sampling must be done on plants that are not located in the portion of the plot to be harvested for yield data.

Harvesting

Arrangements for harvesting the plots should be made with the farmer well in advance of the harvest data. If the plots are large, then regular mechanical equipment can sometimes be used, but usually the plots are too small and the errors too large when using the machinery of the farmer for harvesting. Likewise, at harvest time the farmers are too busy with their own work to spend much time with tedious plot work.

Harvesting Alleys and Borders

The first step usually is harvesting the alleys and borders. The crop residue in the alleys and borders can be cut so that there is ready access to the plots. A "weighing station" can be located in the border or alley areas.

Relocating Plots

The plot corners should be relocated in the same manner that the plot was originally laid out by measuring from the permanent

markers. The colored stakes should also be placed in the front of each plot designating the treatment and these checked with the map of the experiment.

Recording Data

In addition to recording weight of the samples harvested from each plot, other information should also be recorded. For example: in harvesting corn, the number of lodged plants, fallen ears, and the number of ears might be recorded. Of course, moisture samples of the harvested crop should also be taken in working with cereals in order to correct the yield data to a standard moisture content.

Too much stress cannot be given to careful work in harvesting plots to avoid errors and to recording complete notes in respect to the various observations on the condition of the experiment, etc. Special data sheets with carbon copies prepared for the experiments, or data books with alternating permanent and carbon tear-out sheets, can be used for recording all data. The original sheet should be placed in the office file. All data records should be clearly marked with the name, address, and a note requesting its return if it should be misplaced.

MAKING DATA CALCULATIONS

Testing the Critical Level

The critical level may be plotted as described by Cate and Nelson in Technical Bulletin No. 1, "A Rapid Method for Correlation of Soil Test Analyses with Plant Response Data," International

Soil Testing Series. The percentage yield on the vertical axis is plotted versus the soil analysis value for the element of interest. Each field experiment will provide one point on a separate graph for each of the three elements being studied. A special form prepared by R. B. Cate, Jr., for the International Soil Fertility Evaluation and Improvement Project is shown in Figure 6.

The percentage yield is calculated by dividing the yield obtained from the treatment receiving the base rate of all the elements except the element of interest by that from the highest yielding treatment which received the base rate of the other elements and some quantity of the element of interest (yield calculated as an average of all replications).

For example; if the element of interest is phosphorus, then:

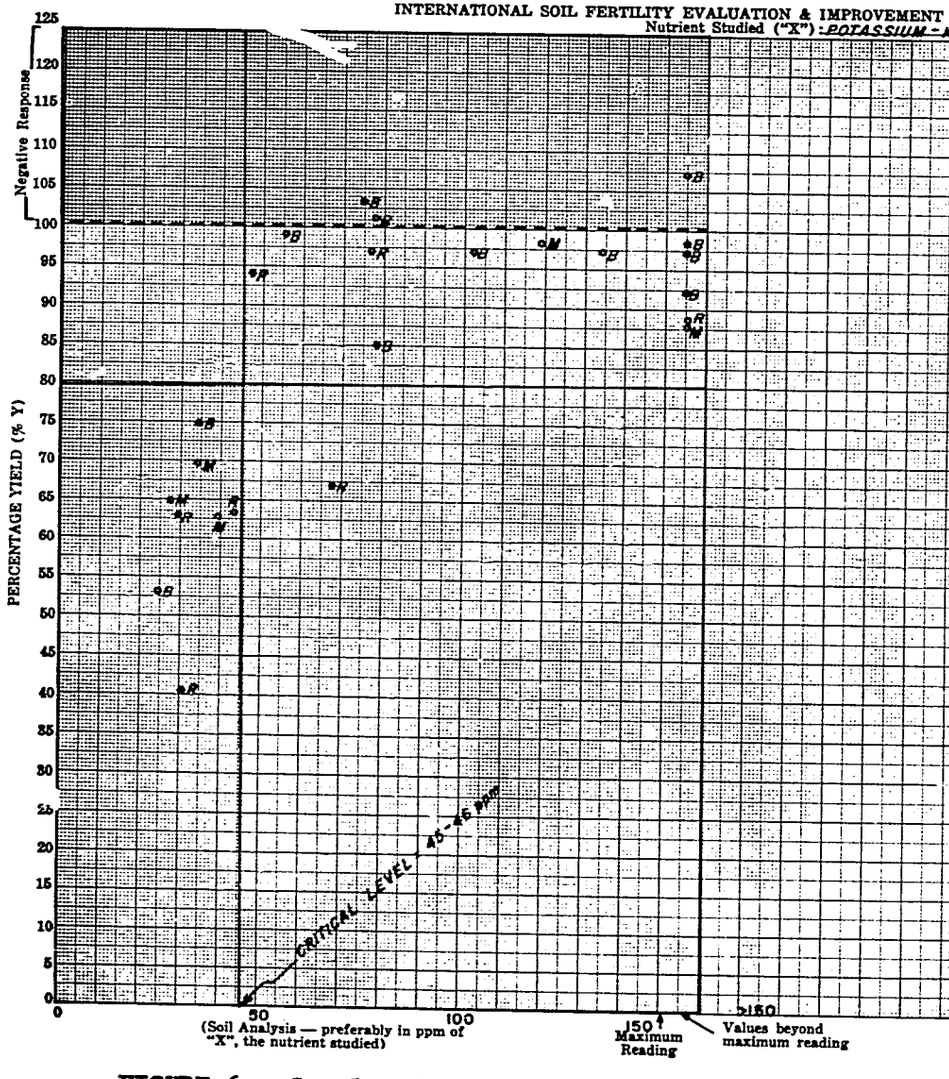
$$\text{Percentage Yield} = \frac{N_B \; P_0 \; K_B}{N_B \; P_B \; K_B} \times 100$$

(or $P_{\frac{1}{2}B}$ or $P_{1\frac{1}{2}B}$)

Prepare a graph with the "Y" axis representing percentage yield, and the "X" axis the soil analysis value. Superimpose on the resulting graph a plastic overlay divided into quadrants. With the lines dividing the quadrants being kept parallel to the axis of the graph, position the overlay so that the maximum number of plotted points are found in the positive or upper right and lower left quadrants. The soil analysis critical level is then defined as the point where the vertical line of the

INTERNATIONAL SOIL FERTILITY EVALUATION & IMPROVEMENT — STANDARD CORRELATION FORM*

Nutrient Studied ("X"): POTASSIUM - K



BASIC DATA TABLE

PERCENTAGE YIELD (% Y)						YIELD OF COMPLETE MINUS "X" / YIELD OF COMPLETE TREATMENT				X - ppm	
SAMPLE NO.	YIELD COMPLETE MINUS "X"	YIELD COMPLETE TREATMENT	%	SOIL ANALY. ppm		SAMPLE NO.	YIELD COMPLETE MINUS "X"	YIELD COMPLETE TREATMENT	%	SOIL ANALY. ppm
C-1	659	875	75	34		FT-2	1131	1166	97	72
C-4	848	1560	54	26		FT-8	1178	1188	86	>150
C-5	3220	3320	97	134		FT-10	834	1045	65	50
C-5a	1113	1138	99	>150		FT-12	1423	1450	98	118
C-6	2256	2325	97	>150						
C-7	1283	1982	65	28						
C-8	1251	1878	67	68						
C-9	2214	2515	88	>150						
C-10	2779	2750	101	78						
C-12	1998	2160	92	>150						
C-14	3042	3142	89	56						
C-15	1115	1080	103	75						
C-5a	1651	1544	107	>150						
C-7	617	822	70	35						
C-15	2404	2827	85	78						
C-16	2543	2621	97	102						
FT-2	979	1042	94	48						
FT-3	674	1644	41	31						
FT-4	856	1337	64	44						
FT-6	847	1345	63	40						

1. Extraction Method (including reagents, normality, time of shaking soil-solution ratio, and whether measurement by weight or volume): HNO3 = 0.05N, 1:10, percolation measured by weight
2. Crop (and variety, if known): Cotton
3. Country and Locations: Brazil - São Paulo
4. Climate: mild tropical
5. Classification of Soils: Latosols Podsols-Roxo (B), Terra Roxa (R), Terra Roxa Misturada (M)
6. Type of Trial (pot, microplot, field, etc.): Field
7. Number of Replications: 4
8. Units of Yield Measurement: Kilos of seed cotton
9. Levels of Nutrients in "Complete": 100 kg/ha N, P_2O_5, K_2O + S + Zn
10. Method of Application of Nutrients: band at planting 2/3 N broadcasting
11. Details on Liming (if any): Dolomitic lime to raise pH to 6.0
12. Code Used in Graph, (if any): Letters to indicate kind of soil (see 5)
13. Other Comments:
14. Persons and Agencies Responsible: (see 16)
15. Dates of Trials: 1958-59 & 1959-60 seasons (see dash line in table)
16. Literature Reference (if published): "Determination of Potassium Deficient Areas for Cotton," L. M. M. de Freitas, A. C. McClung, & F. Pimentel Gomes. Potash Review. May 1968.

*For further details, see Technical Bulletins No. 1 and No. 3 of the International Soil Testing Series. To obtain additional assistance, please contact: International Soil Fertility Evaluation & Improvement, P. O. Box 5907, Raleigh, N. C. 27609

FIGURE 6. Sample of completed standard correlation form for determining the critical level.

lines dividing the quadrants intersects the horizontal axis of the graph. For soils which have a soil analysis value less than the critical level, there is a large probability of obtaining a large yield response by the addition of adequate amounts of the nutrient element. For soils which have a soil analysis value greater than the critical level, there is a small probability of obtaining a large yield response by the addition of the nutrient element. Of course, this does not serve as an economical interpretation of the data, but rather as a biological and agronomic interpretation.

Statistical Analysis

From the standpoint of determining the critical level by the Cate-Nelson method, a statistical analysis of the data is not necessary. However, a statistical analysis will be desirable for making comparisons between treatments and for determining if the base rate of application the variable elements was well chosen.

A simple analysis of variance assuming four replications and twelve treatments would be as follows:

Source	d. f.
Replication	3
Treatments	11
Error	33

This analysis merely indicates whether real differences exist between treatments and gives an indication of the variability encountered.

A more meaningful analysis would require subdividing the treatments as follows:

For treatment scheme 1

Source	d. f.
Replications	3
Treatments	11
N Rates	3
N Linear	1
N Quadratic	1
P Rates	3
P Linear	1
P Quadratic	1
K Rates	3
K Linear	1
K Quadratic	1
Error	33

An L. S. D. for treatments should be calculated so that any two of the eleven treatment means can be compared.

The analysis for schemes 2, 3, and 4 would be similar except, of course, that only the two elements having four rates of application would be subdivided for linear and quadratic analysis.

If the base rate of an element were properly chosen, then the quadratic equation should fit the yield curve for that element.

If the yield curve has a negative slope, such as sometimes occurs (i. e., where phosphorus is added to soils which are deficient in zinc), this would be indicative of a soil condition which requires research attention.

Data and Information Forms

Since the field experiments outlined will be uniform in nature, the following standard data sheets shown in Figures 7, 8, and 9 have been designed for convenience in recording the information associated with each experiment. Each data sheet should be prepared in duplicate so that the original can be filed in the office as a permanent record, and the copy can be carried to the field.

PUBLICIZING THE INFORMATION

The primary purpose of the field trials is to test the critical level for a given nutrient that has been determined in potted plant and laboratory studies. However, the field trials can also serve as demonstations and may create considerable interest among farmers in the community. The farmer on whose field the trial is being conducted should be given due credit for his cooperative efforts.

Signs

A suitable sign located on the edge of the field may call attention to the trial and, at the same time, give credit by listing the names of the farmer and the cooperating agencies.

Plot Signs

People should not walk through the plots since damage to the plants may result. However, one block or replicate can be marked

DATA SHEET NO. I

GUIDE FOR TREATMENT LEVELS AND AMOUNTS OF MATERIALS TO BE USED PER PLOT

EXPERIMENT NO. _____

SITE LOCATION _____

PRELIMINARY SOIL ANALYSIS FOR SITE SELECTION

pH	O.M.	P ppm	K ppm	LIME REQUIREMENTS Tons/Acre	FIXATION QUANTITY X LB/ACRE	
					P_2O_5	K_2O

CROP TO BE GROWN _____ DATE TO BE PLANTED _____

SIZE OF INDIVIDUAL PLOT _____

RECOMMENDED RATE/ACRE FOR BASE TREATMENT

N	P_2O_5	K_2O	LIME	OTHERS			

NO.	TREATMENTS	WEIGHT OF MATERIAL PER PLOT						
		N	P	K	OTHER			
1	N_0 P_0 K_0	0	0	0				
2	N P K							
3	N P K							
4	N P K							
5	N P K							
6	N P K							
7	N P K							
8	N P K							
9	N P K							
10	N P K							
11	N P K							
12	N P K							
TOTAL PER REPLICATION								
TOTAL PER EXPERIMENT								

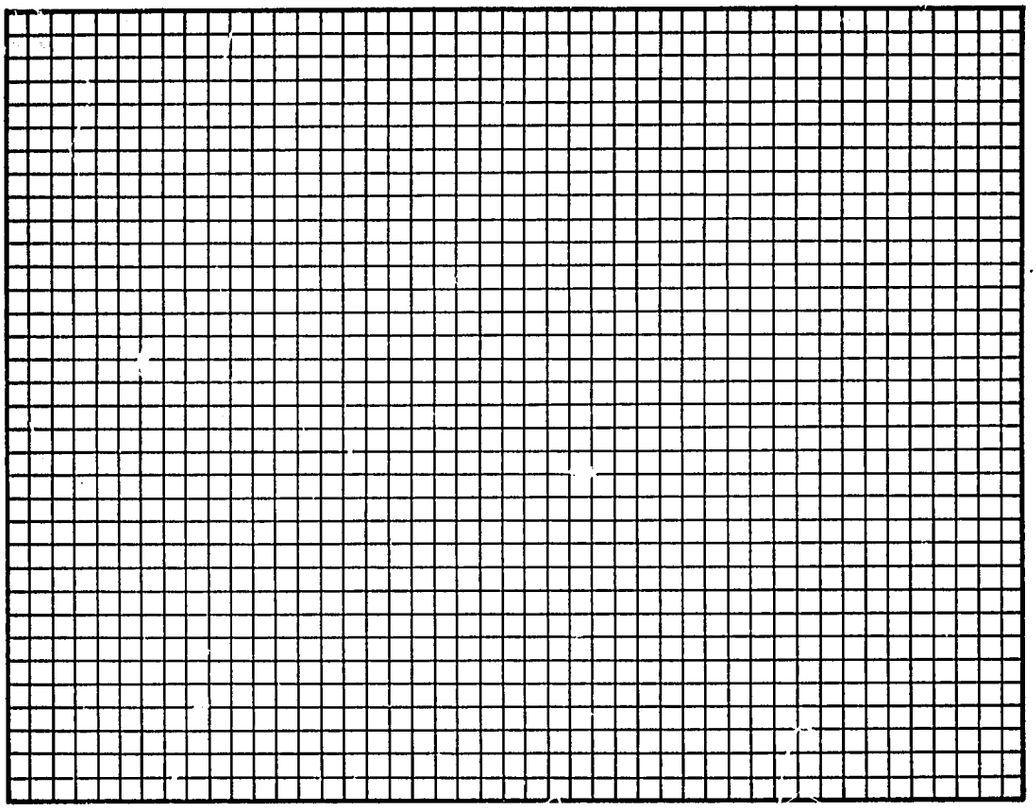
FIGURE 7.

DATA SHEET NO. 2

MAP AND OBSERVATION SHEET

EXPERIMENT NO._____SITE LOCATION_____

Indicate measurements to landmarks, stakes, etc., which are used for locating the corners of experimental site and individual plots.



Remarks:

Observations during growth:

FIGURE 8.

DATA SHEET NO. 3

RANDOMIZATION OF THE PLOTS AND DATA OBTAINED FOR FIELD EXPERIMENT

EXPERIMENT NO._____ LEADER_____ YEAR_____

FARMER_____ LOCATION_____

ADDRESS_____ TELEPHONE NO._____

CROP_____ VARIETY_____

DATE PLANTED_____

DATE HARVESTED_____

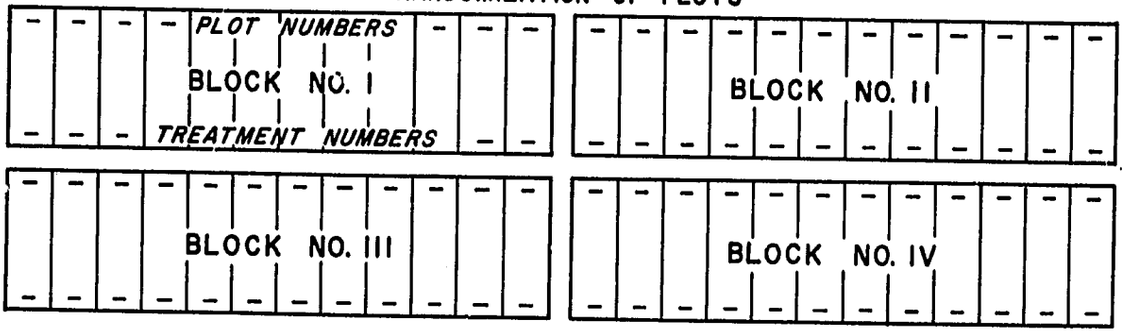
SOIL DESCRIPTION_____

_____

_____

SOIL ANALYSIS	pH	% O.M.	P ppm	K ppm	OTHERS		
BLOCK I							
BLOCK II							
BLOCK III							
BLOCK IV							
METHOD							

RANDOMIZATION OF PLOTS



YIELDS BY BLOCKS

TREATMENTS	I	II	III	IV
1 N_0 P_0 K_0				
2 N P K				
3 N P K				
4 N P K				
5 N P K				
6 N P K				
7 N P K				
8 N P K				
9 N P K				
10 N P K				
11 N P K				
12 N P K				

FIGURE 9.

with the treatments and will serve as a demonstration for visitors to observe.

Field Meetings

"Seeing is believing" is an old adage. If several field trials are involved, a tour may be arranged for the public to view them. Another possibility is to have several small meetings at one or two of the sites. Meetings or tours should be arranged when the plots are in good condition and differences are apparent. If the meetings are held at harvest time, all blocks should be harvested previously except possibly one. Then weight data can be presented. During the harvest season, however, farmers are busy with their own harvests; and with a number of field trials to harvest, there may not be time for holding meetings.

Photographs

Pictures speak louder than words, and plans for obtaining a series of photos at various stages of the experiment are an important part of the experiment. Photos should be taken during the planting procedure, at different stages of growth, and at harvest. Group pictures of meetings are also important. The pictures should be taken for use in publications as well as slides for educational meetings.

Publication

No research is complete until the data are interpreted and published. This is as important as conducting the experiment. In

preparing plans for experiments, publication should be a part of the consideration. The data obtained will be helpful not only to the local program but to other areas as well. The information can be used also in educational programs.