

# Symposium on Soil Testing

The eight papers which follow comprise the Symposium on Soil Testing presented on September 15, 1959, at the 136th National Meeting of the American Chemical Society at Atlantic City, N. J., by the Society's Division of Fertilizer and Soil Chemistry.

The symposium was designed to:

outline the history and bring up to date the known technology of soil testing;  
describe current research aimed at improving the accuracy and usefulness of soil-testing techniques;

point the way for future progress, in order that soil testing may be made increasingly effective as a diagnostic tool, assuring more efficient use of lime and fertilizers, and more profitable production of crops and livestock.

The division was fortunate in securing participation of a distinguished panel of experts. Each member of this group of able scientists has specialized in some aspect of soil testing and interpretation, and offers specific knowledge in his selected field.

The symposium as a whole, therefore, covers soil testing both intensively and extensively; it provides useful information at all levels from basic research to practical application.

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## History and Development of Soil Testing

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The history and development of soil testing are considered in three approximate periods: 1845 to 1906, 1906 to 1925, and 1925 to 1952. Phosphorus and potassium are emphasized, but other elements are considered. Data of the second period provide background information for interpretation of soil tests. More recently many new methods have been developed, some for universal application and others for specific problems.

FOR a little more than a century soil and plant scientists have sought chemical and biological methods for determining the fertility of a soil. These procedures have often in recent years been related to recommendations issued by governmental agencies for fertilizer practice. The composition of crops has also had an important place in diagnosing the capacity of a soil to deliver nutrients to plants, particularly to crops to be grown subsequently in a field.

The present discussion divides history and development into three imperfectly defined periods. The first is from 1845 to 1906. Review here deals essentially with the work of four authors: Daubeny, Liebig, Hilgard, and Dyer. During the second period, roughly 1906 to 1925, emphasis was placed on the fundamental

chemical composition of soils as related to crop production. A third period includes essentially 1925 to 1952, with ramifications extending to the present. This was a period of struggle for methods that could be universally applicable, and of efforts to adapt chemical procedures to specific soil conditions.

### Early Work

One of the first records of quick soil tests for an assay of soil fertility is that of Daubeny in England in 1845 (6). He suggested the terms "active" and "dormant" to express the more and less soluble nutrient constituents of a soil, respectively. The solvent used for extracting the active portion was carbonated water. Analytical methods in use

more than a century ago imposed difficulties in carrying out the suggestions of Daubeny; and the subject of soil testing appears to have been essentially laid aside until revived by Liebig about a quarter century later (14).

The procedure used by Liebig included extraction of soil with dilute solutions of hydrochloric, nitric, and acetic acids. Varying quantities of phosphorus and potassium compounds were dissolved by the different acids and the quantities dissolved also varied with the manurial treatments received by the soils. The soils used by Liebig were from the Rothamsted Experiment Station, where fertilizer histories had been known for nearly 30 years.

In 1906 when Hilgard wrote the first edition of his textbook (11, p. 353), he

stated that "the soils of Mississippi containing less than about 0.1% of total phosphoric oxide ( $P_2O_5$ ) usually respond well to applications of phosphatic fertilizers, while those containing more than this amount are not likely to respond profitably to such treatment."

This was more than 50 years ago. Farmers now have better seed for various kinds of crops; they know more about the use of fertilizers and expect higher average yields. It is well, however, to consider the importance of this approximate total value, 0.1%  $P_2O_5$ .

This figure provides a yardstick with which to judge a few values in the next items of literature to be examined. In 1894 the first really modern approach to soil testing as a guide for fertilizer practice was made by Dyer (8), who worked with soils from the famous Broadbalk and Hoos Fields of the Rothamsted Experiment Station. The plots had then been under observation nearly 40 years.

Dyer has long been known partly on account of his study of the acidity and nutrient composition of root sap as a guide for the selection of a solvent for active or available nutrients. Analytical methods in use at that time were presumably not suitable for a detailed study of acidity essential for carrying out his thesis. He was, however, led to the selection of 1% citric acid as a solvent. This extractant has been used to some extent for several decades.

The data of Dyer show that the quantity of phosphorus dissolved by citric acid is more closely related to crop production than is the total quantity of phosphorus present. The data show much more pronounced phosphorus deficiency than need for potassium. Dyer's paper contains extensive data of interest to anyone investigating soil tests (Table I).

### Fundamental Chemical Data

Turning now to the second period, 1906 to 1925, fundamental chemical data are emphasized. This is background information and never was proposed as a substitute for quick tests of soil in individual fields. In some of the states the value of chemical composition as background information is recognized; in other states little attention is paid to these older data.

There is a great volume of data from Iowa showing the phosphorus contents of soils of that state by counties, published in 1914 (5). Certain soils of a glacial till area in the northeastern part of the state were shown often to contain about 0.1%  $P_2O_5$  in the surface soil and less in the second foot. Soils of the loess area in western Iowa often contain approximately double the amount of  $P_2O_5$  found in the glacial till area of the north-east. These data are confirmed by

analyses published in 1940 (23). The Iowa station has properly placed its sub-station for the evaluation of phosphate rock *vs.* superphosphate in an area of the Carrington-Clyde soil association of northeastern Iowa. These soils frequently have a  $P_2O_5$  content of about 0.1% in the surface soil and less in a layer beneath plow depth.

Arkansas has soils of tremendous contrast in phosphorus content and consequently of recommended use of phosphatic fertilizers. A splendid publication of that state gives data of interest in characterizing the phosphorus status of a number of its soil types (27). Table II shows the total phosphoric oxide content of surface soils and subsoils of several series found in Arkansas. The low values indicate where phosphate rock can frequently be used economically for building up the inventory of total phosphorus in the soil.

In Kentucky, soils of the Maury series in the Inner Blue Grass Region usually have  $P_2O_5$  contents of 0.75 to 2.5%. Phosphatic fertilizers are not needed. Less than 100 miles distant is the Knob Country, where soils of medium texture often have  $P_2O_5$  contents of less than 0.1% (13). In these areas small grain production is sometimes hopeless without phosphatic fertilizers.

The three states mentioned provide excellent chemical information regarding their soils; each also has a very effective soil-testing service. The background data aid in the interpretation of results obtained from tests of soils sent in by farmers.

Sometimes background data help considerably when the highly desirable tests for more readily available constituents are not obtainable. Kaddah (12) has shown that the phosphoric oxide content of suspended matter of the lower Nile River ranges from 0.21 to 0.35%. This type of mud has provided the soil material where the grain grown 6000 years ago presumably fed a vast number of people who built the pyramids.

We have a Biblical record of some 2500 years ago when the Hebrews sent a small committee to Egypt to buy grain during a famine in Palestine. About the same time Pericles, the great Greek statesman, showed some embarrassment over the political necessity of receiving a gift of "corn" from the Egyptians. The Nile Valley always produced good small grain crops because the water supply was assured, and the muds deposited had left a soil with at least 0.2% phosphoric oxide (9, 12). On the other hand, many soils of Greece have less than 0.1%  $P_2O_5$  (2).

With respect to phosphorus-bearing minerals, apatite is of common occurrence in soils, but it is very insoluble in water and the  $P_2O_5$  content is very slowly available. Other forms of calcium phosphate containing some fluorine

**Table I. Barley Yield and Phosphoric Oxide Contents of Surface Soils Differently Treated, Hoos Field, England**

Soil Treatment	Barley Grain Yield, 38th Year (1890) Bushels	Average of 4 plots (8)	
		Phosphoric Oxide Contents of Soils, %	
		Total	Soluble in 1% citric acid solution
No minerals	24.7	0.10	0.006
N, $K_2O$ , and $MgO$ , no phosphates	24.4	0.11	0.009
N, $P_2O_5$ , $K_2O$ , and $MgO$	38.6	0.18	0.050
N and $P_2O_5$ , but no $K_2O$ or $MgO$	36	0.18	0.043

**Table II. Total Phosphoric Oxide Content of Surface Soils and Subsoils of Arkansas (21)**

Soil Series	$P_2O_5$ , %	
	Surface soil	Subsoil
Baxter	0.06	0.04
Lufkin	0.03	0.02
Atkins	0.09	0.06
Leaf	0.03	0.02
Portland	0.17	0.14
Sharkey	0.18	0.15
Miller	0.18	0.13
Hanseville	0.07	0.06

are also found in soil. When phosphatic fertilizers are applied to land, extensive residues of varying composition accumulate. It is not surprising that the quantities of phosphorus extracted by different solvents at various soil-solution ratios show wide variations.

The potash situation is very different from that of phosphorus with respect to response to testing solutions. Most of the methods are dependent upon base exchange principles set forth by Way (29) more than a century ago. The concentration and pH of an extracting solution, as well as soil-solution ratio, usually have only moderate influence on the amount of potash extracted. Furthermore, the amount extracted is greatly influenced by the general composition of the soil.

In many cases the total potash content of a soil bears very little relation to available potash status. Climatic conditions which affect natural leaching appear to be of great importance. Many soils of the Piedmont area extending from New England into Georgia are well supplied with  $K_2O$ ; values as high as 2 to 2.5% occur in soils of medium to heavy texture (4). On these soils potassium fertilizers are frequently economically used.

**Table III. Readily Available Phosphorus Obtained from Soils of Fertility Plots, Arostook Farm, Maine (24)**

Description of Soils	Readily Soluble Phosphorus, Lb. P <sub>2</sub> O <sub>5</sub> /Acre				Truog Values Divided by Values as Indicated				
	Truog	Modified Morgan (15-18)	2.5% acetic acid	Hester (10)	Neubauer	Modified Morgan	2.5% acetic acid	Hester	Neubauer
Virgin soil	62	9.5	19	1.3	...	6.5	3.3	47.7	...
No treatment, 3-yr. rotation	73	5.8	21	1.5	...	12.6	3.5	48.7	...
4-8-8, 2000 lb. in 3-yr. rotation	200	13	87	2.0	100	15.4	2.3	100.0	2.0
4-12-8, 2000 lb. in 3-yr. rotation	300	17	150	2.6	130	17.6	2.0	115.4	2.2
4-8-8, 2000 lb. continuous potatoes	400	24	220	3.2	200	16.7	1.8	125.0	2.0

Fertilizer potash added for one crop may be partly taken up by the crop and partly leached out during a year. A large part may also be fixed by contact with minerals such as micas; these losses may be partly compensated by the decomposition of potash-bearing minerals and organic matter.

### Recent Work

In 1951 a report issued by a National Soil Testing Committee (19) summarized methods used in various state and other institutional laboratories. At that time 28 laboratories used the same type of extracting solution for available soil phosphorus as for potassium. Strong mineral acids were used in concentrations varying from 0.02*N* to 0.3*N*. Varying kinds and concentrations of buffering salts were used in a few cases with the acid.

Any of these extractants may be expected to produce conventional base exchange reactions when an adequate quantity of liquid is used. The action on phosphorus-carrying compounds is no doubt rather drastic when the more concentrated solutions of mineral acids are used.

The Bray (3) or Illinois test for phosphorus employs ammonium fluoride with hydrochloric acid as an extractant. It may be assumed that the fluoride ion tends somewhat to separate the phosphate and silicate radicals that are related chemically.

Water as a solvent was proposed by Spurway of Michigan (26), and later used in certain other areas, particularly for soils not strongly leached. It would seem that carbonated water, a slightly more effective solvent than pure water, has met with a little more favor, though not extensively used.

A buffered solution, such as sodium acetate with acetic acid at a pH of approximately 5, has been widely used as an extractant for potassium and less extensively for phosphorus.

Soil-solution ratio is one of the extremely important features for estimating results in terms of pounds of available phosphorus present per acre. These ratios vary from 1 to 2 for several methods to 1 to 40 in Oklahoma when a particular extractant is used for both phosphorus and potassium (79). The

soil-solution ratio is usually the same for each nutrient.

Some confusion has arisen as to which of the Truog methods for extracting phosphorus from soils should bear his name. Apparently, the one published in 1930 (27) was the one he first suggested, as it has frequently been designated as the Truog method (24). The distinctive feature of this procedure is that it employs 0.002*N* sulfuric acid neutralized to pH 3.0 after addition of 3 grams of ammonium sulfate per liter. The soil-solution ratio is 1 to 200. Advantages of a wide soil-water ratio are discussed by Truog (28).

Many kinds of solutions for extracting available phosphorus from soils have been proposed. Several of these were compared by Rubins and Dean in 1946 (24). References to some original publications are given in Table III. The data given here are taken from Rubins and Dean or calculated from their data. A few conclusions are apparent:

The highest phosphorus values are obtained with the Truog procedure. Two factors may be assumed to be important: the low pH of the extracting solution, and the wide soil-solution ratio employed.

The Hester procedure leads to the smallest amount of phosphorus extracted, but the Morgan method (78) also gives relatively low values. The main difference between these two procedures lies in the slightly higher pH of the Hester solution and a soil-solution ratio of 1 to 2 instead of 1 to 4 as in the Morgan procedure.

The 2.5% acetic acid solution gave results nearest to the absorption of phosphorus by rye plants (Neubauer method). This does not mean, however, that some other plant would follow a like pattern.

It may be assumed that any of these sets of values may be helpful in arriving at the phosphorus status of a soil. Additional useful information might often be obtainable if two or more kinds of tests were made on a particular soil.

One of the more recently described methods for available phosphorus involves extraction by a solution of sodium bicarbonate (22). This type of solution was first used for alkaline western soils, but is applicable to acid soils as well. Miller and Axley extracted phosphorus from 17 soils of Maryland, using four different extracting solutions. The

sodium bicarbonate procedure usually gave lowest values (76).

Soil-test data, gradually accumulated for a little more than a quarter of a century, have steadily become more useful in interpreting probable fertilizer needs. Relations of test results to soil types and to kinds of crops grown are of particular importance.

In 1932 Scarseth conducted a series of experiments in Alabama (25) that are of great value in showing the effects of soil type and time elapsing after fertilizer application in rendering soluble phosphates less available to plants. The experiment was not designed as an aid to interpreting quick test data for local recommendations, but such data can be used in this way as background information.

Another series of experiments valuable as background is that of De Turk (7) and others in Illinois. Sweet clover made more effective use of the phosphate rock than did wheat. It has not yet been shown, however, which of the soil test methods thus far proposed is most suitable for use when a field has been treated with a heavy application of phosphate rock. It is possible to use a factor smaller than 1 to diminish values by the Truog or other strong acid method. Or a factor greater than 1 might be used against values obtained with a nearly neutral sodium acetate solution at a narrow soil-solution ratio.

Even if the original thesis of Dyer, developed more than a half century ago, could be fully realized, there is little reason to believe that an extracting solution of conductivity and pH similar to that of the sap of roots and plants could be effectively used. The big question of soil-solution ratio would still be unsolved. Furthermore, the composition of plant sap no doubt varies widely with kind of plant grown. Other complicating factors are also operative here.

It has long been known that soil test data furnish only a part of the information necessary for proper interpretation of results in terms of the most profitable fertilizer practice (7, 20). Such data increase in value as supplemental information is at hand. The necessity for such supplemental information has led to a practice in many laboratories of securing a record of field practice.

Questions such as these are frequently sent to the farmer with a soil container:

What sequence of crops was grown during the past three years?

If commercial fertilizer, farm manure, or lime was added, what was the rate of application of each and the grade of fertilizer?

What was the approximate yield of each crop?

Were crop residues left on the soil in so far as practicable?

A soil map is usually in the office of a county agricultural agent. Furthermore, he travels over the county extensively and observes farm practice and crop yields. In many counties a number of farms are supervised by farm managers who visit fields at frequent intervals. Records of their experience are often available for inclusion with the soil data and other information gathered from varied sources.

The emphasis of this presentation has been upon phosphorus, partly because of the wide differences in values obtained using different tests. Potash and nitrogen should not be neglected, however. The various base exchange processes used should lead to results less variable with potash than with phosphorus.

The question to be decided is not so much whether or not phosphorus, potash, or nitrogen is needed, as what level will prove most profitable for a particular crop. A grower of cotton in any one of several of the southeastern states knows that he usually needs some potash for growing his crop most profitably. Should he apply 40 or 60 pounds of  $K_2O$ , for instance? The laboratory test to be an

effective aid in answering this question must be supplemented by extensive local data. Time and observation aid in the accumulation of helpful information.

Modern features of soil testing are international in scope. Prominent among those working in this field in different countries are Egner of Sweden, Ferrari of the Netherlands, and Turin of the Soviet Union.

Instrumentation, using such equipment as the flame photometer and the spectrograph, is under way and seems destined for expansion. Minor element studies have been expanded by instrumentation and deserve further consideration in the field of soil tests.

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## Research in Maryland on Chemical Methods for Determining Available Phosphorus and Potassium in Soils

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FARMERS in recent years have shown an active interest in soil testing. A survey by the Federal Extension Service showed that nearly a half million more soil samples were tested by state and county soil testing laboratories in 1957 than in 1955. Also a nationwide survey based on personal interviews revealed that soil testing was rated by farmers as the most important single external influence in their fertilization practices (19).

About 2,600,000 tons of phosphate ( $P_2O_5$ ) and 1,900,000 tons of potash ( $K_2O$ ) are processed in the United States each year (16). A more intelligent use

of these two fertilizer elements could result through the development of improved soil tests. Although much progress has been made in the development of soil-test methods, many of the tests need to be correlated more extensively with crop response data. In many cases the soil-test correlation data have been obtained from experiments designed for other purposes and there has been a lack of control of the many factors that determine plant growth. As a result the correlation data and calibration scales that have been obtained can in many cases be improved upon.

A number of chemical extraction methods for determining available phosphorus and potassium in soils have been used by soil-testing laboratories in this country. To determine under Maryland conditions the correlation of several soil-test methods with crop response data, a pot culture experiment and several field experiments were conducted. This research has been helpful in evaluating some methods used by soil-testing laboratories, but a great deal more soil-test correlation work is needed for crops and soil conditions that exist in Maryland.