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.

A number of chemical extraction methods have been used in this country for determining available phosphorus and potassium in soils. A pot culture experiment and several field experiments were conducted in Maryland to determine the correlation of several methods with crop response data. In many instances there was little difference between the correlation coefficients for chemical methods used to determine available phosphorus. When all the soils in the investigation were considered, a method employing sulfuric acid and ammonium fluoride as an extractant showed the closest relationship with crop response. The soil series determined to a large extent the correlation between chemically available phosphorus and alfalfa yields. The thermal method proposed by Kolterman and Truog showed promise for determining the relative capacity of soil to supply nonexchangeable potassium to plants.

Materials and Methods

Chemical Extraction Methods. Soluble phosphorus was determined in the soils by the modified Truog method (*13*), the Bray and Kurtz No. 1 method (*2*), the sodium bicarbonate method of Olsen *et al.* (*10*), the Wrenshall and McKibbin method (*20*), the North Carolina method (*4*), and the proposed method of Miller and Axley (*9*). Potassium was determined by the North Carolina method and the proposed method of Kolterman and Truog (*5*).

Field Pot Culture Experiment. A pot culture experiment which consisted of 17 Maryland soils each treated with 20% superphosphate to obtain five levels of soluble phosphorus was conducted at the University of Maryland Plant Research Farm. This experiment was designed as a randomized complete block with five treatments replicated three times on each soil and was used to determine the correlation of phosphorus soil tests with crop response. More specific information on the experimental procedures used in the pot culture experiment, is given by Miller and Axley (*9*).

Field Experiments. The response of crops to phosphate applications was available from field experiments on a Beltsville silt loam, a Monmouth fine sandy loam, and a Penn loam. The response of tobacco to potassium was also available on the Monmouth fine sandy loam. In the field experiments the soil samples were taken from the surface 6 inches of the plots. The fertilizer treatments and the chemical methods employed to determine phosphorus and potassium are shown in Tables V, VII, IX, and X.

Results and Discussion

The phosphorus extracted from the soils in the pot culture experiment by the various chemical methods is shown in Table I. In general, the greatest quantity of phosphorus was extracted by the proposed method of Miller and Axley, which employs 0.03*N* sulfuric acid and 0.03*N* ammonium fluoride as an extractant. The sodium bicarbonate method removed the smallest quantity of phosphorus from the soils, while the modified Truog and Bray and Kurtz No. 1 methods were intermediate and on the average removed about the same amounts of phosphorus. The phosphorus removed from the Chester soil in this experiment by three chemical methods is shown in Figure 1. Similar curves were obtained for several soils. A number of workers (*1, 7, 12, 15*) have reported that the various chemical methods for available phosphorus extract widely different amounts of phosphorus from the same soil. However, this does not present a serious problem as long as the phosphorus extracted shows a good relationship to crop response. For example, the phosphorus extracted by the proposed method averaged about 30% greater than that extracted by the modified Truog method; yet the correlation coefficients obtained for the phosphorus extracted and the crop response data for the pot culture experiment were very similar for the two methods.

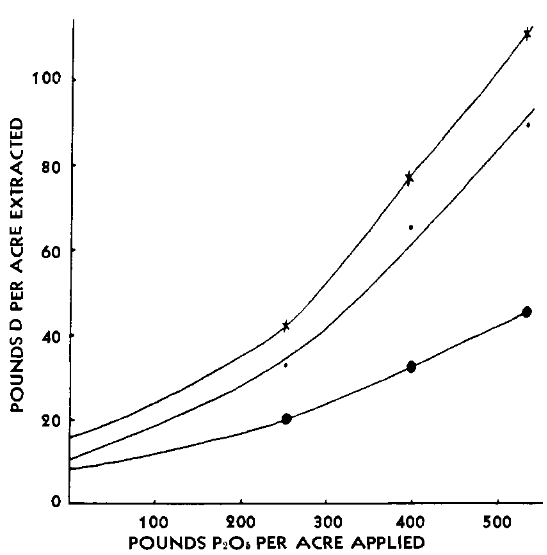

Figure 1. Relation between phosphorus extracted from Chester loam by three chemical methods and phosphate applied to soil

X Proposed method
• Modified Truog
● Sodium bicarbonate

The Galestown, Hagerstown, and Sassafras soils gave no increase in the yields of wheat in the pot culture experiment due to phosphate applications. When alfalfa was the test crop, the same three soils and the Westphalia did not show any response to phosphate applications. The soils that showed no response to phosphorus usually contained a higher level of extractable phosphorus (Table I). The levels of phosphorus in the soils at which phosphate applications often failed to increase the yields of alfalfa and wheat were: 55 pounds per acre, modified Truog; 55, Bray and Kurtz No. 1; 55, North Carolina; 35, sodium bicarbonate; and 70, proposed method.

The correlation coefficients obtained

for all the variables associated in Table II were significant at the 1% level. However, the r^2 values show that much of the variance in yield was related to factors other than soluble phosphorus as determined by the chemical methods. The phosphorus removed by the alfalfa showed a closer relationship than the yield of alfalfa with the phosphorus extracted by the different chemical methods, because at the higher levels of soil phosphorus the plant continued to absorb phosphorus even after there was no further increase in yield. In previous work conducted at this station the "sufficiency value" for phosphorus in alfalfa was estimated to be 0.20% (*8*). On a number of soils at the higher soil phosphorus levels the alfalfa contained considerably more than this quantity of phosphorus.

The correlation coefficients for the phosphorus extracted *vs.* the yields of alfalfa on each of the soils in the pot culture experiment are shown in Table III. Because a plot of the data from this experiment showed that the relationship between extractable phosphorus and yield appeared to be logarithmic rather than linear, the number of pounds of phosphorus extracted per acre was expressed as a logarithm. A comparison of the over-all correlation coefficients for soil phosphorus *vs.* alfalfa yields in Tables II and III bears out this relationship. In many instances there was little difference between the correlation coefficients for the various methods on the same soil. In this investigation the soil series apparently determined to a large extent the relationship between soluble phosphorus and yields of alfalfa. For example, the correlation coefficients calculated for the Bray and Kurtz No. 1 method ranged from 0.120 to 0.885, depending upon the soil type being studied. In a number of cases the soils which gave a poor correlation were high in extractable phosphorus and showed little or no response to phosphate applications. The over-all correlation coefficients for the 17 soils, which included 255 observations, ranged from 0.318 for the Bray and Kurtz No. 1 method to 0.461 for the Truog method. The low values for the over-all correlation coefficients can be explained on the basis that the yield and yield response were not the same for all the soils. The situation was somewhat improved when correlation coefficients were determined for the relationship between soluble phosphorus and yield within soils. The correlation coefficients then ranged from 0.585 to 0.602, which means that the variation in extractable phosphorus accounted for 34 to 36% of the variation in yield within a soil. It is evident that the soil series determined to a large extent the correlation between soluble phosphorus and yields of alfalfa and this apparently must be taken into consideration for more reliable fertilizer recommendations. Data of Olson, Dreier, and Sorensen (*11*) clearly indicate the importance of both soil series classification and soil testing for the most reliable recommendations possible.

The approximate amounts of superphosphate needed to establish similar levels of chemically available phosphorus in the soils in the pot culture experiment varied considerably (Table IV). Toth and Bear (*18*) also showed that there were wide differences in the phosphorus-absorbing capacities for soils in New Jersey. Properties such as texture and type of clay mineral influence markedly the amount of phosphate that must be applied to a soil to establish a certain level of soluble phosphorus. In this experiment the Belts-

Table I. Phosphorus Extracted by Chemical Methods from Soils in Pot Culture Experiment without Added Superphosphate (9)

	Phosphorus Extracted by 4 Methods, Lb./Acre			
Soil Type	Modified Truog	Bray and Kurtz No. 1	Sodium bicarbonate	Proposed method
Atkins loam	14	23	14	25
Beltsville loam	7	13	7	13
Calvin loam	14	15	13	20
Chester loam	10	14	8	15
Christiana clay loam	7	10	7	13
Collington sandy loam	24	48	22	53
Conowingo loam	9	9	8	11
Galestown sand	81	94	29	116
Golts silt loam	26	73	29	93
Hagerstown loam	74	39	30	50
Lehew sandy clay loam	36	26	17	34
Manor sandy loam	9	14	11	19
Montalto clay loam	7	11	11	13
Myersville loam	18	11	11	16
Penn sandy loam	18	16	10	23
Sassafras loamy sand	81	75	28	101
Westphalia sandy loam	33	55	20	66

Table II. Correlation of Soluble Phosphorus, Determined by Chemical Methods, with Yield, and Phosphorus Removed by Alfalfa in Pot Culture Experiment (9)

	Correlation Coefficients[a] for 4 Methods			
Crop Variable	Modified Truog	Bray and Kurtz No. 1	Sodium bicarbonate	Proposed method
Total yield of alfalfa for two cuttings	0.295	0.212	0.195	0.251
Phosphorus removed by alfalfa	0.522	0.495	0.421	0.516

[a] Calculated from 255 observations which included soils from 17 soil series; calculations significant at 1% level.

Table III. Correlation between Logarithm of Pounds of Soluble Phosphorus per Acre Measured by Chemical Methods and Total Yield of Alfalfa for Two Cuttings in Pot Culture Experiment (9)

	Correlation Coefficients[a] for 5 Methods				
Soil Series	Modified Truog	Bray and Kurtz No. 1	Sodium bicarbonate	N. C. method	Proposed method
Atkins	0.675[b]	0.602[c]	0.591[c]	...	0.636[c]
Beltsville	0.842[b]	0.834[b]	0.833[b]	0.829[b]	0.835[b]
Calvin	0.742[b]	0.751[b]	0.727[b]	...	0.749[b]
Chester	0.545[c]	0.531[c]	0.545[c]	0.536[c]	0.538[c]
Christiana	0.794[b]	0.799[b]	0.773[b]	...	0.774[b]
Collington	0.740[b]	0.739[b]	0.725[b]	0.720[b]	0.712[b]
Conowingo	0.827[b]	0.816[b]	0.804[b]	...	0.843[b]
Galestown	0.242	0.241	0.265	...	0.263
Golts	0.609[c]	0.584[c]	0.580[c]	...	0.578[c]
Hagerstown	0.134	0.120	0.108	...	0.104
Lehew	0.526[c]	0.525[c]	0.485	...	0.518[c]
Manor	0.895[b]	0.885[b]	0.876[b]	...	0.884[b]
Montalto	0.705[b]	0.692[b]	0.705[b]	0.706[b]	0.700[b]
Myersville	0.707[b]	0.676[b]	0.724[b]	0.703[b]	0.706[b]
Penn	0.347	0.388	0.359	0.381	0.348
Sassafras	0.268	0.191	0.194	...	0.179
Westphalia	0.253	0.268	0.238	...	0.156
Total for 17 soils	0.461[b]	0.318[b]	0.344[b]	...	0.359[b]
Within 17 soils	0.601[b]	0.601[b]	0.585[b]	...	0.602[b]

[a] Calculated for each soil series from 15 observations; total for 17 soils and within 17 soils calculated from 255 observations.
[b] Significant at 1% level.
[c] Significant at 5% level.

ville loam and Montalto clay loam contained the same levels of Truog phosphorus (Table I), yet the superphosphate required to establish 60 pounds of soluble phosphorus in these two soils by the modified Truog method varied by more than 1500 pounds per acre. Cole and Olsen (*3*) have also shown with calcareous soils that the soil texture affects phosphorus solubility.

The yields of alfalfa and phosphorus extracted from a Penn loam by several chemical methods are given in Table V. The application of 200 pounds of P_2O_5 increased the yield of alfalfa by almost 2 tons per acre. The phosphorus extracted by the modified Truog method and proposed method from the plots receiving this treatment was about 14 pounds per acre greater than that for the no-phosphate plots.

The influence of different phosphate carriers on the yields of corn, wheat, and red clover grown on a Beltsville silt loam is shown in Table VI. Application of equal quantities of P_2O_5 supplied by superphosphate and rock phosphate showed the superphosphate to give larger yields of corn, wheat, and red clover hay. The modified Truog, Wrenshall and McKibbin, and North Carolina methods extracted more phosphorus from the soils treated with rock phosphate (Table VII) than was readily available to the plants, as indicated by the yields of corn, wheat, and red clover. For example, the modified Truog method extracted three times more phosphorus from the rock phosphate–treated plots than from the superphosphate-treated plots which received the same quantity of P_2O_5; yet the yields of all the crops grown were less when rock phosphate was used. Other workers (*14*, *17*) have also noted this difficulty with acid extractants when rock phosphate has been used on soils. It is evident that one cannot make a reliable phosphate recommendation when using these chemical methods unless the past treatment of a soil is known. The correlation coefficients for phosphorus extracted from the Beltsville silt loam by several chemical methods and the yields of corn for 1953 and 1954 are given in Table VIII.

The phosphorus and potassium extracted from a Monmouth fine sandy loam and the yields and value of tobacco are shown in Tables IX and X. The correlation coefficients obtained for the phosphorus and potassium extracted from the soils by the North Carolina method and the yields of tobacco were significant at the 1% level. The r^2 values show that with the phosphorus soil test, 90% of the variation in the yield of tobacco was accounted for and with the potassium test 71%.

Legg and Axley (*6*) have studied the thermal method proposed by Kolterman and Truog for determining fixed potassium in soils. The data obtained by these workers suggest the possibility of using the thermal method for determining the relative capacity of soils to supply nonexchangeable potassium to plants (Table XI). A single heating and extraction treatment was as effective as a series of successive treatments in this regard.

Table IV. Approximate Quantities of Phosphate Needed to Establish Several Levels of Soluble Phosphorus in Soils by Modified Truog Method

Soil Type	Truog Phosphorus Level and P_2O_5 Applied,[a] Lb./Acre 40	60	80	100
Penn sandy loam	60	130	210	260
Collington sandy loam	120	240	320	400
Beltsville loam	210	340	440	520
Myersville loam	220	360	480	600
Chester loam	280	390	480	570
Montalto clay loam	410	650	800	960

[a] 20% superphosphate used to supply phosphorus.

Table V. Yields of Alfalfa and Phosphorus Extracted from Penn Loam by Chemical Methods (9)

Soil Treatment,[a] Lb./Acre P_2O_5	K_2O	Alfalfa Yield,[c] Tons/Acre	Phosphorus Extracted by 4 Methods,[b] Lb./Acre Modified Truog	Bray and Kurtz No. 1	Sodium bicarbonate	Proposed method
0	600	2.06	8	6	6	12
80	600	3.51	14	14	10	18
200	600	3.93	21	13	14	26
400	600	3.66	52	38	29	59
L.S.D. at 0.05 level		0.45	..	..	..	..
L.S.D. at 0.01 level		0.59	..	..	..	..

[a] 20% superphosphate and 60% KCl used to supply P and K.
[b] Average of 4 replicates.
[c] Average annual yield from 4 replicates at 14% moisture for 1951 and 1952.

Table VI. Yields of Corn, Wheat, and Red Clover Hay on Beltsville Silt Loam as Influenced by Phosphate Carriers (9)

Soil Treatment[a]		Crop Yields[b] 1953		1954	
Source	P_2O_5 applied, lb./acre	Center section corn, bu./acre	South section hay, tons/acre	Center section wheat, bu./acre	South section corn, bu./acre
Superphosphate	75	38.0	3.41	30.0	86.7
Rock phosphate	75	34.0	3.05	24.1	75.0
	300	41.5	3.24	27.0	85.3

[a] All plots received annual application from 1952 to 1954 of 100 pounds of K_2O per acre and 45 pounds of N for wheat and 100 pounds for corn. Plots that received annual application of 75 pounds of P_2O_5 per acre from 1952 to 1954 received 50 pounds annually from 1941 to 1951, and plots that received 300 pounds of P_2O_5 annually from 1952 to 1954 received 200 pounds annually from 1941 to 1951.
[b] Each value represents average for superphosphate of 4 replicates and for rock phosphate of 3 replicates.

Conclusions

There was often little difference between the correlation coefficients obtained for the various chemical methods used to determine phosphorus in the soils. However, when all the soils in the investigation (those treated with rock phosphate or superphosphate) were considered, a proposed method employing sulfuric acid and ammonium fluoride as an extractant apparently showed the closest relationship with crop response. When the soils receiving rock phosphate were not considered, the modified Truog method gave the highest correlation with crop response data of all soluble phosphorus methods studied. However, on rock phosphate–treated soils, the Truog and other methods employing acid extractants removed more phosphorus from the soils than was readily available to the plants as indicated by the yields.

In the pot culture experiment the soil series determined to a large extent the correlation between phosphorus extracted by the different methods and the yields of alfalfa. The quantities of 20% superphosphate required to establish similar levels of chemically available phosphorus in these soils varied in some cases by a ton or more.

The levels of extractable phosphorus in the soils for the different chemical

Table VII. Phosphorus Extracted by Chemical Methods from Beltsville Silt Loam Treated with Superphosphate and Rock Phosphate (9)

	Phosphorus Extracted by 6 Methods, Lb./Acre											
	Sodium Bicarbonate		Bray and Kurtz No. 1		Proposed Method		Wenshall and McKibbin		Modified Truog		N. C. Method	
Soil Treatment[a]	C[b]	S[b]	C	S	C	S	C	S	C	S	C	S
Superphosphate,[c] 75 lb. P_2O_5/acre	15	21	22	29	37	42	25	36	25	33	36	45
Rock phosphate[d]												
75 lb. P_2O_5/acre	3	8	5	10	12	18	48	48	86	88	128	125
300 lb. P_2O_5/acre	9	13	14	16	27	29	149	152	260	276	472	506

[a] See footnotes[a], Table VI, for treatment history.
[b] C center section; S south section.
[c] Each phosphorus value represents average of 4 replicates.
[d] Each phosphorus value represents average of 3 replicates.

Table VIII. Correlation of Soluble Phosphorus Determined by Chemical Methods with Yield of Corn for 1953 and 1954 on Beltsville Silt Loam Treated with Superphosphate and Rock Phosphate (9)

Chemical Method	Correlation Coefficient[a]
Modified Truog	0.123
North Carolina method	0.165
Wrenshall and McKibbin	0.233
Bray and Kurtz No. 1	0.284
Sodium bicarbonate	0.394
Proposed method	0.436

[a] Correlation coefficients calculated from 20 observations. At 5% level $r = 0.444$.

Table IX. Yields and Value of Tobacco and Phosphorus Extracted from Monmouth Fine Sandy Loam by North Carolina Method

P_2O_5 Applied, Lb./Acre	Tobacco Yield,[a] lb./acre	Tobacco Value, $/acre	Phosphorus Extracted Lb./Acre
0	803	259	13
30	876	420	24
90	942	429	46
180	1000	482	88

[a] Average annual yield for 6 years from 4 replicates. Phosphorus extracted *vs.* yield of tobacco, $r = 0.949$. Significant at 1% level. Cooperative project between University of Maryland and U. S. Department of Agriculture.

Table X. Yields and Value of Tobacco and Potassium Extracted from Monmouth Fine Sandy Loam by North Carolina Method

K_2O Applied, Lb./Acre	Tobacco Yield[a] lb./acre	Tobacco Value, $/acre	K Extracted, Lb./Acre
0	750	350	151
60	846	465	205
120	892	508	311
240	928	603	490
300	917	637	638

[a] Average annual yield for 6 years from 4 replicates. K extracted *vs.* yield of tobacco, $r = 0.840$. Significant at 1% level. Cooperative project between University of Maryland and U. S. Department of Agriculture.

Table XI. Nonexchangeable Potassium Removed by Cropping and by Single Heating (500° C.) and Extraction Treatment (6)

Soil	By First Heating and Extraction Treatment, P.P.M.	By Prolonged Cropping, P.P.M.
Sable	610	613
Herrick	345	332
Wooster	242	217
Hagerstown	240	128
Decatur	207	122

methods at which phosphate applications often failed to increase the yields of alfalfa in the pot culture experiment were: 55 pounds per acre, modified Truog; 55, Bray and Kurtz No. 1; 55, North Carolina; 35, sodium bicarbonate; and 70, the proposed method.

The correlation coefficient for the relation between potassium extracted from a Monmouth soil by the North Carolina method and the yields of tobacco in a field experiment for a 6-year period was significant at the 1% level. In this same experiment the phosphorus extracted also showed a close relationship with tobacco yields.

The thermal method proposed by Kolterman and Truog showed some promise for determining the relative potassium-supplying power of soils.

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Paper A803, Contribution 3074, Maryland Agricultural Experiment Station (Department of Agronomy).

Correction

The Toxicology of Butoxypolypropylene Glycol 800 (Crag Fly Repellent)

In this article by C. P. Carpenter, C. S. Weil, P. E. Palm, M. D. Woodside, and H. F. Smyth, Jr. [J. AGR. FOOD CHEM. **7,** 763 (1959)], on page 763, the sentence beginning in the eighth line of the abstract should read, "It is not stored in the bodies of animals, and 50% or more of a single dose may be found in the feces unchanged."