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DISTRIBUTION OF PHOSPHORUS IN THE SOIL SEPARATES

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by

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It is a matter of common observation that soils of a clayey nature are more productive than sandy soils, and those who are versed in the science of agriculture know that the physical properties of a soil, determined by the relative proportions of coarse and fine material, are as important a factor of production as the chemical fertility. The most prominent effects attributable to the texture of a soil are that too much of the fine material will cause a soil to puddle and is also responsible for poor under-drainage, while, on the other hand, too much sand will form a soil that has poor water holding capacities. But this is not the only way in which the texture of a soil influences its productivity. Our conception of soil formation from the parent rock includes the process of pulverization by the many agencies associated with rock disintegration. As the weathering of the rocks progresses, we have solution and erosion. On account of the varying densities of the products of weathering, erosion may be a selective process through which some minerals are left in greater abundance than others. We know that the soil minerals have different rates of solution, but does it necessarily follow that the more soluble ones will be removed by leaching? For instance, the mineral, apatite, is relatively soluble, but the phosphorus compounds that are liberated are reprecipitated in the soil as the phosphates of iron and aluminum. In making a mechanical separation, these would appear in the fine material and thus influence the composition of the clay. Finally, we know that some minerals are more resistant to weathering than others, and so, in geologically new regions, where this process is still in its infancy, we should expect to find the more resistant minerals in the form of larger grains. May not these or other factors, chemical, physical, or mineralogical, tend to cause a concentration of the essential plant food elements in either the coarse or the fine material ?

In order to obtain data bearing upon this question, Loughridge, then of Mississippi, began the work of analyzing the fine material in the soil.* This was in 1874, and the work has subsequently been continued by other investigators. The most notable, extensive, and systematic investigation was undoubtedly made by the Bureau of Soils of the U. S. Department of Agriculture, and the results are published in their Bulletin No. 54. This thesis is merely an additional study of the same question with reference to phosphorus, since it is the element most likely to be deficient in soils. This study differs from most previous ones in that virgin soils were used. The attempt was also made to find a constant relationship between the phosphorus content and the texture.

A brief resumé of previous work on this subject is not amiss. Loughridge, Schneider, Meyer, Tolman, and Schloessing made some analyses with a view to making comparisons between the separates of the soil.* Each used a method of his own in the mechanical separation, and so their results are not readily comparable. Furthermore, all of them used some conventional strength hydrochloric acid in the digestion and then determined the phosphorus in the extract. This was merely an experiment on the relative solubility of the soil separates in concentrated hydrochloric acid, and re-

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*Bulletin No. 54, Bureau of Soils, U. S. D. A.

vealed nothing concerning the ultimate composition. Since the amount dissolved by any solvent varies as the amount of surface of the solute exposed to it, the clay must have given the highest results in every case. Their results cannot, therefore, be used for comparisons in connection with total composition.

Orth, however, made a total analysis by the hydrofluoric acid decomposition method, but recalculation of his results merely makes it possible to compare the whole soil with its finest part and to conclude that the latter has the higher percentage of phosphorus.*

Puchner worked with a heavy loam soil, a loamy loess, and a coarse sandy gneiss soil. He used only the separates of less than 0.25 mm. in diameter and separated these into four classes and then made total analyses on these separates. From the results he concludes that the content of lime, magnesia, and phosphoric acid in the various separates is irregular.*

The Bureau of Soils separated the soils into sand, silt, and clay and then made total analyses for phosphorus, potassium, calcium, and magnesium on each separate. The technique of their method and also of the one employed in this thesis study is such that all of the organic matter soluble in dilute ammonia water and all the soluble salts of the soil will appear in the clay separate. In this manner, the Bureau analyzed 7 soils from the Coastal Plains province, 3 residual soils derived from crystalline and metamorphic rocks, 10 soils of glacial origin, 5 soils derived from limestones and shales, and 2 from the arid regions, and published their results in Bulletin No. 54. These results will be

*Bulletin No. 54, Bureau of Soils, U. S. D. A.

used later for comparisons with results obtained in this study. The general conclusions arrived at by the Bureau were that:

1. The smaller particles of the soil are generally richer in the critical elements than the coarser material.
2. The concentration of these elements in the fine material becomes greater as the soil is more thoroughly weathered.
3. In glacial soils and others resulting from mechanical processes, the coarser particles are relatively high in the plant food elements.
4. A comparison of the soil and the soil separates with the composition of the parent rock indicates an increase in the phosphorus content and a decrease in the other critical elements.

DESCRIPTION OF THE SOILS USED

Three samples of virgin soil were collected in Vilas County, Wisconsin,- two sands and a fine sandy loam. These are glacial soils, deposited by glacial streams in formations known as out-wash aprons. They are underlaid by coarsely crystalline rocks of the Archean Period in which the dominant minerals are horneblende, quartz, feldspars, micas, and pyroxenes. In the upper peninsula of Michigan about 50 miles to the northeast, the direction from which the glacier came, there is an area of ferruginous sandstone. Transportation of material from this area may have occurred and may account for the high iron content of these soils. All three soils have level to gently undulating topography.

Sand # 1 is light brown in color to a depth of about 6 inches except the surface 2 inches, which contains a little humus and leaf mold. Below 6 inches and to a depth of three feet the color is yellow. Pebbles and cobbles are sometimes found on this soil, but this tract was free from them. The soil is loose and incoherent , so that drainage is excessive, and if the rainfall were not so evenly distributed the soil would suffer from drouths. The land has been deforested and later swept by fires. The native vegetation on this soil consists of Norway and Jack pine, scrub oak, sweet fern, blueberries, wintergreen, and rarely a few scraggly poplar.

Sand # 2 lies near and not far above the surface of Rest Lake, and so the water table is near the surface. This makes the vegetation of this soil more like that of a heavier one. It comprises Norway pine, small poplar, birch, and some maple trees, sweet fern, blueberries, and wintergreen. In other respects it is similar to sand # 1.

The fine sandy loam has a surface 3 inches of a gray fine sandy loam, underlaid by about 4 inches of a brown fine sandy loam. The sub-soil is a light brown fine sandy loam. This area has never been lumbered except to remove the white pine and has never been swept by fires. The native vegetation consists of hemlock, white pine, oak, birch, maple, and basswood. Pebbles are abundant on this tract.

The samples were collected in the field by taking about 10 cores to a depth of 8 inches with a soil auger, using care in selecting a typical spot and removing the leaf mold on the surface. This composite sample was placed in a canvas sack, labeled, and shipped to the laboratory.

DETAILS OF THE ANALYTICAL METHODS

The composite sample was dried in the laboratory, weighed, pulverized with a rubber tipped pestle, and run through a sieve, having 20 meshes to the inch. The coarse material was weighed, and the percentage calculated on the dry basis. The 20-meshed soil was riffled, and duplicate 10 gram samples were weighed into tared aluminum dishes and dried at 110 degrees C. in an electric oven for at least 36 hours. They were cooled in a dessicator, weighed, and the loss in weight calculated to percentages of moisture on the dry basis. At the same time that these samples for the moisture determination were weighed out, duplicate 10 gram samples were weighed out on a watch glass for mechanical analysis. In taking this soil material from the whole sample, the horn spatula was filled heaping full and then leveled off with a steel spatula. This was done so as to avoid the error that would be introduced by the large sand grains rolling off from a heaping spatula full of soil. By means of a 4 inch funnel and a stream of distilled water from a wash bottle, the sample was transferred rapidly, easily, and without loss by dusting to an 8 ounce shaker bottle. The bottle was filled to the 3 ounce mark, 1 cc. of Conc. ammonium hydroxide was added, the bottle was stoppered with a rubber stopper, and shaken in the mechanical shaker over-night. Since the separation of the sand from the silt and the clay was to be made by sedimentation, it was necessary to determine the length of time required for all soil particles above 0.05 mm. in diameter to settle. This was accomplished by means of a microscope fitted with an eye-piece micrometer, and the time found to be 1-1/12 minutes. Accordingly, the bottle was shaken thoroughly, allowed to stand 1-1/12 minutes, and the supernatant liquid with the silt and clay in suspension was poured into a centrifuge tube and centrifuged for such a length of time as would separate the silt from the clay. With the aid of the microscope,as before, it was found that 1¾ minutes of centrifuging were required to throw down the particles of more than 0.005 mm. in diameter. The supernatant liquid carrying the clay in suspension was poured into a 2 liter bottle. The shaker bottle was refilled with ammonia water to the 3 ounce mark (5 cc. of ammonia to one liter of distilled water), shaken and poured off as before into the centrifuge tube. In all but the first decantation, it will be necessary to stopper the tube with a rubber stopper and shake up the silt. The stopper is removed and the tube is again centrifuged. This washing and decantation is continued until the supernatant liquid in both the shaker bottle and the centrifuge tube is clear after the proper period of sedimentation or centrifuging has been allowed.

The silt is then transferred quantitatively to a previously tared evaporating dish and dried, first on the steam bath and finally in the electric oven at 110 degrees C., and weighed. The clay was shaken up well in the two liter bottle and measured, and an aliquot portion is dried just as the silt was and weighed. The sand is dried at 110 degrees also and is then run through a set of the Bureau of Soils sieves, great care being exercised to make a quantitative sifting. These sieves separate the sand into five grades,- fine gravel, 2.0 to 1.0 mm.; coarse sand, 1.0 to 0.5 mm.; sand, 0.5 to 0.25 mm.; fine sand, 0.25 to 0.1 mm.; and very fine sand, 0.05 to 0.1 mm. These grades of sand are again dried at 110 degrees in tared aluminum dishes and weighed. All results are reported on the oven-dry basis, using the results obtained in the moisture determination for calculating the dry weight of the sample. Duplicate results are averaged, and the average given in table I.

Using this same method of separation, a 200 gram sample of each of the three soils was separated into sand, fine sand, silt, and clay. This gave sufficient material for the chemical work. The sands were dried and ground in an agate mortar and then run through a 100 mesh sieve in preparation for chemical analysis. The mortar had to be covered with a piece of card-board with a hole in the center for the pestle, in order to prevent the sand from jumping out of the mortar. The silt was dried and 100-meshed. The clay had to be ground before running it through the 100 mesh sieve, and this was a difficult operation on account of the flaky nature of the clay as it comes out of the evaporating dish. These 100-meshed samples were now ready for chemical analysis.

The chemical work should have included the determination of calcium, potassium, magnesium, and phosphorus, but due to the fact that only one person was available for this work only the phosphorus determination was made. It was carried out according to the following method:

Duplicate 2 gram samples were weighed out on a watch glass and transferred to an iron crucible into which there had previously been placed 5 to 6 grams of sodium peroxide. At the same time a 5 gram sample was weighed into a tared aluminum dish for a moisture determination in order to obtain the dry weight of the sample. To the sand separates in the crucible there was added about .05 grams of pulverized sugar to provide organic matter for the oxidation. This was not necessary for the clay. The materials in the crucible were thoroughly mixed with a dry glass rod, avoiding getting more than necessary on the sides of the crucible. The charge in the crucible was carefully warmed around the edges and then ignited on the surface. As soon as the reaction started, the cover was placed on the crucible and the flame removed until the reaction was completed. It was heated for fifteen minutes at a dull red heat. Fusion should not take place, but in the case of the clay a complete melt was formed on account of the high content of organic matter.

After cooling, the crucible was placed into a 400 cc. beaker and about 100 cc. of water added slowly. After about 5 minutes, or when the material in the crucible had been dissolved, the crucible was rinsed off, and then the entire mass was transferred to a 400 cc. casserole, and 75 cc. of 1 to 5 nitic acid added through the lip of the casserole, the latter being covered with a watch glass. Then it was digested on the steam bath until all the carbonates were completely decomposed, the cover glass removed and the mass evaporated to dryness. It was dehydrated in the hot air oven at 110 to 120 degrees C. until no smell of nitric acid was given off. It is best to allow the evaporation of the gelatinous silica to go to dryness, or it will be difficult to drive off the nitric acid in the hot air oven. 12 to 20 cc. of concentrated nitric acid were added by means of a pipette, and the mass was digested on the steam bath until all the iron had gone into solution. Then about 40 cc. of water were added, the silica ground up with a pestle, and filtered off until the washings were no longer acid to litmus paper. Then ammonium hydroxide was added slowly with stirring until the solution changed color or until a slight permanent precipitate formed. It was acidified with nitric acid until the color disappeared and evaporated to a volume of 125 cc. It was heated to 75 degrees C. and 25 cc. of molybdic solution added, stirring well, and allowed to stand for about 24 hours, and then it was filtered and washed with a solution containing 3% ammonium nitrate and 1% nitric acid. It must not stand much longer than 24 hours or moybdic oxide will precipitate.

The precipitate of ammonium phospho-molybdate was purified by dissolving and reprecipitating as follows: Warm, dilute, ammonium hydroxide (1 vol. conc. NH_4OH to 9 vols. water) was poured onto the filter paper and the solution caught in a 300 cc. Erlenmeyer flask. The washing was done with hot water. To the filtrate were added 3 grams of ammonium nitrate and 3 cc. of molybdic solution to insure an excess of the latter, and then it was evaporated to a volume of about 50 cc. It was heated to 60 degrees C. and nitric acid added slowly from a burette until a yellow color appeared, and then just 1 cc. more of nitric acid was added, agitating the contents continually. The flask was shaken for three minutes and allowed to stand for three minutes more and then immediately filtered onto a 590 filter. The precipitate was washed seven times with 3% ammonium nitrate and 1% nitric acid solution, and finally with pure water until the washings from the flask and the filter were no longer acid. This can be tested by means of a few drops of phenolphthalein indicator and a drop of the sodium hydroxide solution to be used in titrating, or by means of blue litmus paper.

The filter paper and precipitate were returned to the same flask, leaving the filter paper in as loose a form as possible, and dissolved in standard sodium hydroxide solution, the excess of which was then titrated with standard HCl. The amount of the alkali to be added will depend on the amount of the precipitate and the strength of the alkali. Before titrating with HCl, the filter paper was shaken to a pulp and about 25 cc. of water and ½ cc. of phenolphthalein indicator were added. The titration was made over a piece of white paper. The strength of HCl was 2/25 N., and from this the amount of NaOH in 1cc. can be calculated. 1 cc. of sodium hydroxide solution, containing .0059355 grams per cc., is equivalent to 0.2 mgms. of phosphorus. All results were reported on the oven dry basis.

STATEMENT AND DISCUSSION OF DATA

The mechanical analysis shows one of these soils to be a fine sandy loam, and the other two are sands. The results are given in table I.

TABLE I.- MECHANICAL COMPOSITION OF THE THREE SOILS

Separate	Sand No. 1.	Sand No. 2.	Fine Sandy Loam
Fine Gravel	.75	.34	.63
Coarse Sand	23.44	24.68	8.81
Medium Sand	29.65	28.52	10.31
Fine Sand	18.68	18.47	18.54
Very Fine Sand	7.51	9.17	24.60
Silt	9.88	10.88	22.85
Clay	9.63	6.92	14.52
Total	99.54	99.48	100.26

Each of these separates was not analyzed, but the fine gravel, coarse sand, and medium sand were grouped into one composite sample; and the fine sand and the very fine sand formed the second group; silt, the third; and clay, the fourth. The phosphorus content of these four components is given in table II.

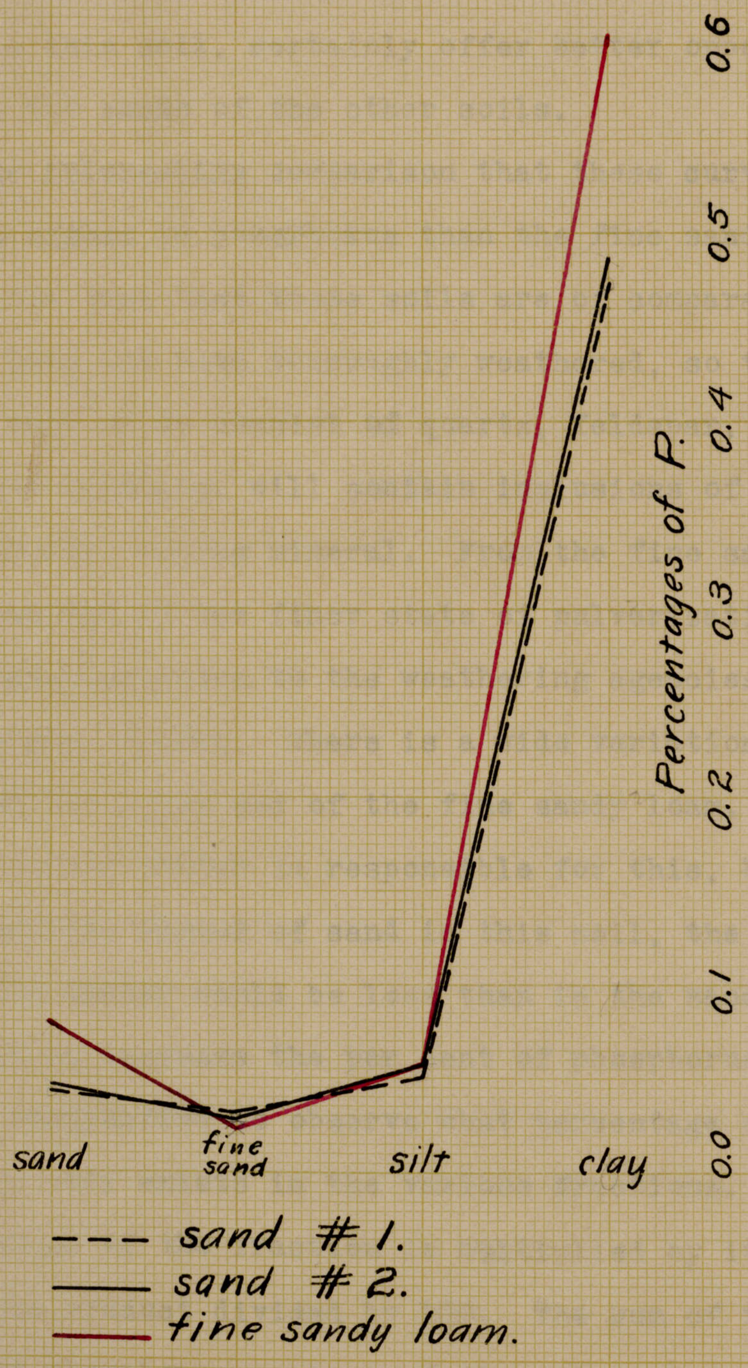
TABLE II.- PHOSPHORUS CONTENT OF THE DIFFERENT SEPARATES

Fraction	Sand No. 1.	Sand No. 2	Fine Sandy Loam
Sand	.0468 %	.0406 %	.0785 %
Fine Sand	.0262	.0303	.0236
Silt	.0578	.0519	.0578
Clay	.4851	.4735	.6043

This fact is represented graphically on Plate 1. A glance at the table and the curve will show that there is a concentration of the phosphorus in the clay, it having approximately ten times as high a percentage as any other separate. The clay of the fine sandy loam has 0.12 % more phosphorus than that of the sands. There may be two explanations of this fact. First, it may be due to a larger amount of soluble organic matter in this soil, but the color of the soil did not indicate a large amount of humus and so it is probably due to some other cause. The weathering of the parent rock sets the phosphorus free in some soluble form, and in the presence of iron or aluminum it is reprecipitated with hardly any loss through leaching as the insoluble iron and aluminum phosphates. Naturally, these would exist in a finely divided state and so would be separated out mechanically as clay. This would, of course, occur in the other soils also; the second explanation

PLATE I.

Phosphorus Content of the Separates.



does not have this objection to it. The silt and the clay, which occur in this soil in a larger ratio than in the sands, may hold some of the available phosphates mechanically by adsorption. Now, it is readily conceivable that the larger the area the greater will be the amount adsorbed, and the silt and the clay, which occur in such abundance in this soil, certainly offer better opportunity for this than do the sands of the other soils.

Another interesting comparison that these curves show is that the sand is higher in phosphorus than the fine sand. This can be explained by the fact that these soils are of comparatively recent origin and have not been thoroughly weathered, so that the large grains of sand which consist of quartz, feldspar, horneblende, mica, and pyroxene crystals, will contain inclusions of apatite or some other phosphorus bearing mineral. From the fine sand, these inclusions, on account of the finer state of pulverization and the consequently greater exposure to the weathering agencies, have been more completely removed. There is a wide variation in the sand separates of the sands and of the fine sandy loam. Perhaps the unhumified organic matter is responsible for this, because, on account of the smaller amount of sand in this soil, the proportion of sand to organic matter would be less than in the sandy soils and so would tend to increase the per cent of phosphorus.

It is instructive to observe what percentage of the total phosphorus in the soil exists in the various fractions. To obtain this, the percentage of the fraction is multiplied by its phosphorus content and the pruduct divided by 100. The sum of these four is the calculated phosphorus content of the original soil; all of this is given in table III.

TABLE III.- PHOSPHORUS CONTENT OF THE SEPARATES CALCULATED TO PERCENTAGES OF THE ORIGINAL SOIL

Separate	Sand No. 1.		Sand No. 2.		Fine Sandy Loam	
	A*	B*	A	B	A	B
Sand	.0252%	30.0%	.0218%	31.8%	.0155%	12.2%
Fine Sand	.0068	8.1	.0084	12.3	.0102	8.1
Silt	.0057	6.8	.0056	8.1	.0132	10.4
Clay	.0462	55.0	.0327	47.7	.0875	69.2
Totals	.0839	99.9	.0685	99.9	.1264	99.9

This table emphasizes the previously mentioned fact that the coarse sand and the clay contain the greater proportion of the phosphorus. Apparently the total phosphorus content is unusually high. In fact, a total analysis of sand #2 by the Wisconsin Soil Survey shows only 0.042% of phosphorus as compared to .0685 as the computed value. It is possible that all the results are too high by approximately the same amount on account of faulty technique, the detection of which occurred too late to remedy it. It is supposed that the precipitate of ammonium phospho-molybdate was not washed entirely free from nitric acid, for the completeness of washing was tested with litmus paper, whereas a drop of alkali in the washings with some phenolphthalein indicator should have been used. Part of the alkali used in dissolving the precipitate of ammonium phospho-molybdate was, therefore, used in neutralizing the nitric

* In every case column A is the per cent of phosphorus of the whole soil and B is the per cent of the total phosphorus in the fraction.

acid thus making the results too high. If this be the case, the error in the total calculated phosphorus would be quadrupled, for the acid was left in four filter papers, each time introducing the error, while in the total analysis there is but one filter paper. Since this error is likely to be the same in all the determinations, the preparation of table IV is still possible.

From the analytical results of the Wisconsin Soil Survey, the following analyses were obtained and tabulated:

TABLE IV.- MECHANICAL COMPOSITION AND PHOSPHORUS CONTENT OF SEVERAL SOILS (Reported as percentages)

Soil No.	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt	Clay	Phosphorus
740	10.17	27.29	39.43	9.18	8.59	5.06	.052
742	13.23	13.99	7.03	19.00	38.25	8.51	.064
743	16.21	30.29	29.28	9.08	8.71	5.91	.042
780	21.62	22.23	15.62	8.86	22.61	9.49	.058
781	11.93	16.03	20.80	17.52	25.71	8.17	.067
784	12.40	25.08	30.64	14.88	10.37	6.49	.063
785	11.17	19.20	28.16	27.29	11.35	3.23	.068
739	12.72	17.20	16.39	14.31	31.16	7.96	.045
847	8.42	10.71	15.92	22.61	33.04	9.41	.074
863	4.40	8.50	46.76	21.45	12.53	6.40	.059
864	14.18	14.42	30.50	16.75	16.93	7.57	.063
869	14.23	21.98	38.80	9.06	9.61	6.18	.053
870	13.38	14.68	27.20	17.01	20.48	7.00	.057
919	24.09	23.83	29.07	5.05	10.32	7.42	.052

Table V expresses the same thing but in more abbreviated form. The percentages of sand, fine sand, silt, and clay, the totals, the calculated phosphorus content, and the total determined phosphorus in the original soil are given. The percentages of the fractions, as determined by the Survey's analysis, are multiplied by their content of phosphorus, as determined in this study. This gives the phosphorus in the fraction expressed as percentage of the whole soil. The sum of these four results of the calculated phosphorus in the fractions is the calculated per cent in the original soil. Let a, b, c, and d represent the percentages of the mechanical components, w, x, y, and z the phosphorus content of the respective fractions, and T the total phosphorus in the original soil. Then, if the phosphorus content of the fractions were the same in the various soils, the following relationship would exist:

$$\frac{aw + bx + cy + dz}{100} = T$$

In preparing this table, the soils were divided into two groups, the first containing all the sands and the second all the sandy loams. To find the computed percent of phosphorus in each soil of the first group, the average composition of each fraction of the two sands was used. For the sandy loam group, the phosphorus content of the fractions of only one soil was available for the calculation.

TABLE V.- COMPARISON OF THE TOTAL WITH THE CALCULATED PHOSPHORUS CONTENT OF SEVERAL SOILS

Soil No.	Soil Class	Sand	Fine Sand	Silt	Clay	Total	Calc. P.	Det. P.
			SAND GROUP					
740	Sand	37.46%	48.61%	8.59%	5.06%	99.72%	.059%	.052%
743	Sand	46.50	38.36	8.71	5.91	99.48	.064	.064
784	Sand	37.48	45.52	10.37	6.49	99.86	.066	.063
785	Sand	30.37	55.45	11.35	3.23	100.40	.049	.068
863	Fine Sand	12.90	68.21	12.53	6.40	99.84	.062	.059
869	Sand	36.21	47.86	9.61	6.18	99.86	.064	.053
919	Sand	47.92	34.12	10.32	7.42	99.78	.072	.052
			SANDY LOAM GROUP					
739	Sandy Loam	29.92	30.70	31.15	7.96	99.74	.097	.045
742	Sandy Loam	27.22	26.03	38.25	8.51	100.01	.100	.064
780	Sandy Loam	43.85	24.48	22.61	9.49	100.43	.110	.058
781	Sandy Loam	27.97	38.32	25.71	8.17	100.17	.096	.067
847	Fi. Sandy Loam	19.13	38.53	33.04	9.41	100.11	.100	.074
864	Sandy Loam	28.60	47.25	16.93	7.57	100.35	.089	.063
870	Sandy Loam	28.06	44.21	20.48	7.00	99.75	.100	.057

The general impression to be gained from this table can be best obtained from a graphical representation, and so the curves on Plates 2 and 3 were prepared. The various soils are arranged along the abscissae and the percentages of phosphorus on the ordinates.

The calculated and the determined percentages of phosphorus in the sand group vary between .049 % and .072 %, but the curves which represent these results converge, cross, and diverge again, and so we must conclude that there is no <u>constant</u> relationship between the texture and the phosphorus content. If there were, the curves would have the same general trend. This statement is corroborated by the curves of the sandy loam group. In this case some disturbing factor has made all of the calculated percentages too high, so that the curve for the determined results was raised an arbitrary distance along the ordinates in order to facilitate comparison. It points toward the same conclusion. Furthermore, if there should be such a constant relationship, the percentage of phosphorus in the separates of each soil would need to correspond closely. Table II shows a wide variation in the phosphorus in the sand and clay fractions of the fine sandy loam as compared to those of the sands. In the calculations for the sand group, these widely deviating results were disregarded, and even then there were large differences between the calculated and the determined phosphorus. The analysis of the fine sand shows a very low phosphorus content and the clay a high one. Hence, in soil # 785 with 55.5 % of fine sand and only 3.2 % clay, the calculated phosphorus content is too low. Undoubtedly, in this case, the fine sand contains more phosphorus than that in the

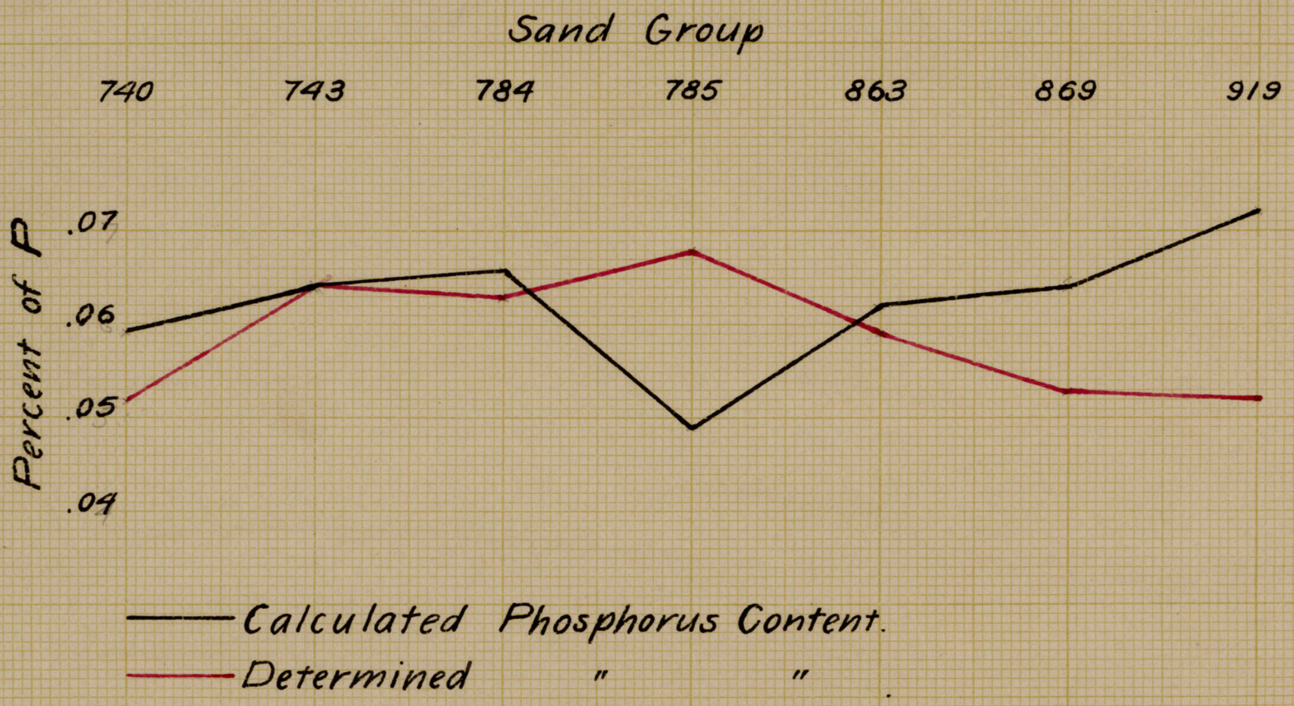

Sand Group
740
743
784
785
863
869
919
Percent of P
.07
.06
.05
.04
Calculated Phosphorus Content.
Determined " "

PLATE 2.

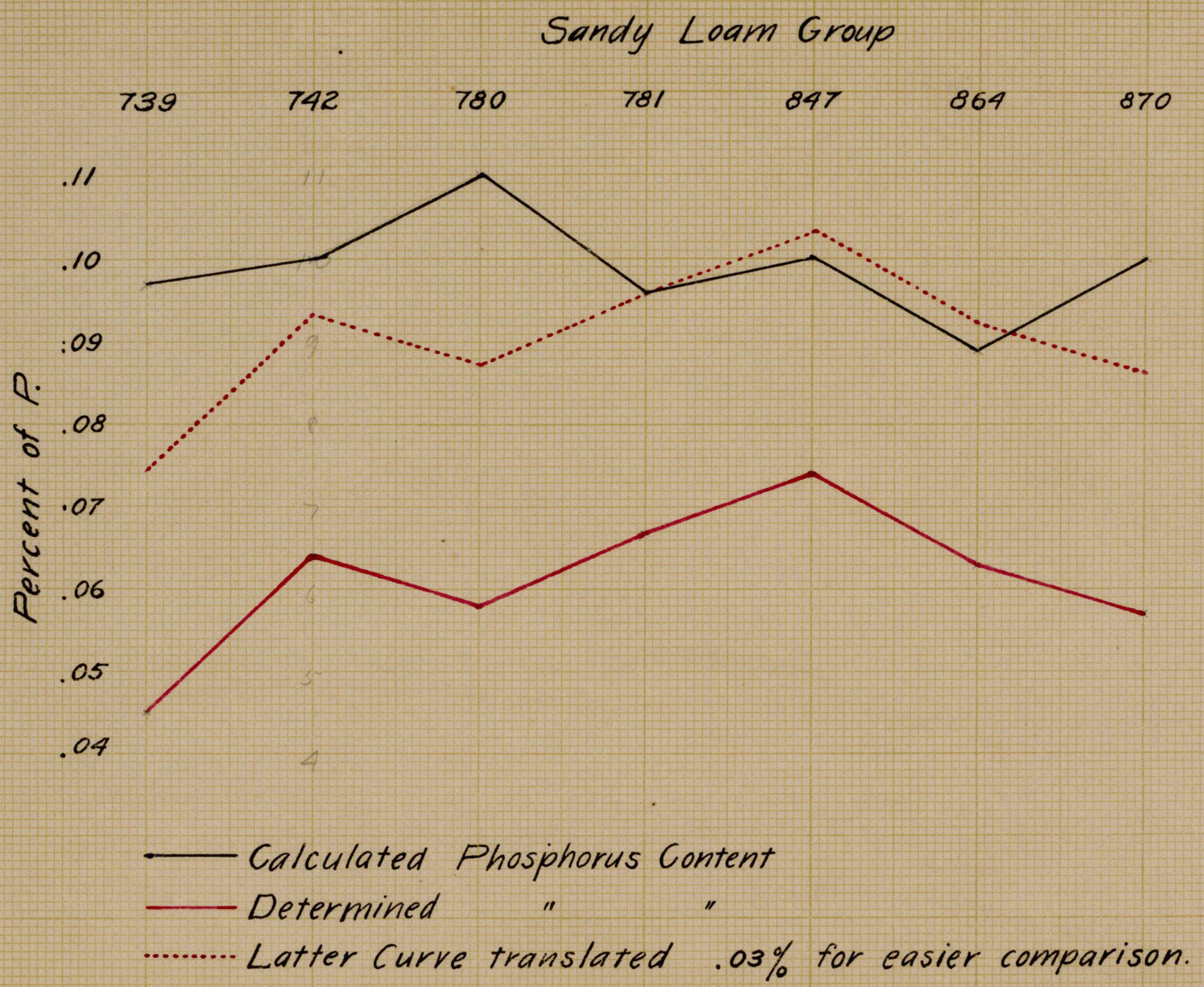

Sandy Loam Group
739
742
780
781
847
864
870
.11
.10
.09
.08
.07
.06
.05
.04
Percent of P.
Calculated Phosphorus Content
Determined " "
Latter Curve translated .03% for easier comparison.

PLATE 3.

soils fractionally analyzed. In the case of soil # 919, the calculated phosphorus content is much too high, because of the large proportion of sand, which is relatively high in phosphorus, and also on account of the fair amount of clay. In this soil, the sand must have had a lower per cent of phosphorus.

The soils used in this study were all virgin soils from the glacial and loessial province, derived essentially from the same rock, deposited in the same manner, and exposed to the same agents of weathering for the same length of time. Yet in spite of these facts and conditions, we find no constant definite relationship between the phosphorus content and the textural composition, and so we may infer from the results of these studies that soils under cultivation to which fertilizers are being added and those of different geological origin would certainly not have such a constant relationship.

The results obtained by the Bureau of Soils confirm this inference, for they find great variations in the phosphorus content of the fractions of soils from within a province as well as in soils from different provinces. Table VI, compiled from the data presented in their Bulletin No. 54, is a comparison of the distribution of phosphorus in the fractions of several loams from different provinces, giving at the same time the per cent of the three components in each soil. 1 & 2 are soils from the Coastal Plains province, 3 is a residual soils derived from crystalline and metamorphic rocks, 4 & 5 are from the Glacial and Loessial province, and 6 is a soil derived from limestones and shales.

TABLE VI.- COMPARISON OF SOILS FROM DIFFERENT PROVINCES

Soil Type and its Location by States.	Sand		Silt		Clay	
	% in Soil	% P	% in Soil	% P	% in Soil	% P
1. Norfolk Loam, Md.	64.5	.004	25.5	.026	9.0	.018
2. Leonardtown Loam, Md.	29.5	.004	55.	.009	15.	.013
3. Porter's Black Loam, Virginia.	53.	.065	23.	.230	24.	.592
4. Wabash Loam, Ohio	50.5	.048	38.	.083	12.	.175
5. Marshall Loam, Minn.	48.	.075	38.	.083	13.	.162
6. Hagerstown Loam, Tenn.	36.	.017	40.	.022	23.	.175

The separates of soils of approximately the same texture but taken from different provinces do not have a similar phosphorus content. The sands vary between .004 % and .075 %, the silts between .009 % and .230 % (or .083 %, if the higher one should be called a freak soil by critics), and the clays between .013 % and .175 %. This difference may be due to the origin of the soil, but, if this is true, we should find soils of the same origin to have fractions whose chemical value is the same, at least the sand and the silt, which are not influenced by the application of manures, etc. But this is not the case as was shown in this thesis and in table VII, taken from Bulletin 54, Bureau of Soils, in which the composition of the fractions of soils from the glacial and loessial province are given.

TABLE VII.- PHOSPHORUS CONTENT OF SEPARATES FROM GLACIAL AND LOESSIAL SOILS

Soil Type and its Location by States	Sand		Silt		Clay	
	% in Soil	% P	% in Soil	% P	% in Soil	% P
Podunk Fine Sandy Loam, Connecticut	80.5%	0.12%	18.0%	0.31%	2.0%	3.36%
Miami Sand, Ohio	91.5	.21	5.5	.51	3.5	1.52
Wabash Loam, Ohio	50.5	.11	38.0	.19	12.0	.40
Volusia Silt Loam, O.	17.0	.09	64.0	.09	19.0	.46
Marshall Loam, Minn.	48.0	.18	38.0	.19	13.0	.37
Miami Silt Loam, Wis.	14.0	.12	72.0	.19	14.0	.56
Marshall Silt Loam, Wis.	12.0	.13	70.0	.24	17.0	.52
Marshall Black Clay Loam, Ill.	21.5	.31	57.5	.32	20.0	.56
Marion Silt Loam, Ill.	13.0	.05	69.0	.08	18.0	.35
Shelby Silt Loam, Mo.	7.0	.19	74.0	.16	19.0	.49

The extraordinary amount of phosphorus in the clay of the Podunk Fine Sandy Loam is explained by the fact that heavy applications of fertilizers were made upon this soil for tobacco raising. "The fine particles of the dust and clay are probably not wholly composed of fine residual parts of the minerals originally composing the soil mass, but are to a greater or less extent made up of newly formed particles of precipitates, or at least of newly formed minerals, which may adhere tenaciously to the fine residual grains or form independent aggregates, which, being disintegrated by the washing of the soil, are obtained in the form of clay," says W. F. Headden.* The Podunk Fine Sandy

* Colorado Bulletin No. 65.

Loam has fixed as "newly formed particles of precipitates" some of the phosphatic fertilizers that have been applied. This "fixing power of the soil is due to the presence of easily decomposable salts of iron, aluminum, and calcium."* The phosphates of these metals are relatively insoluble in water as shown by the Maryland Experiment Station.*

TABLE VIII.- RELATIVE SOLUBILITY OF PHOSPHATES IN PURE WATER

	Parts of Pure Water	
	Ignited	Freshly Precipitated
1 part of $Ca_3(PO_4)_2$	160,000	89,000
1 part of $AlPO_4$		160,000
1 part of $FePO_4$	733,000	161,000

This explains the high per cent of phosphorus in the clay of the Podunk Fine Sandy Loam, but the other mechanical constituents of these soils from the Glacial and Loessial province vary in their phosphorus content in the different soils. The sand separates run between .05 % and .31 %, the silts between .08 % and .51 %, and the clays between .35 % and .56 %.

The variations in the phosphorus content of the fractions of the soils from other provinces show that there is no constant relationship, whether the soil be derived from crystalline or sedimentary rocks, whether it be sedentary or transported, or whether it occurs in the humid or the arid region. So we must

*Bulletin 20, Maryland Station.

agree with Rudzinski in his conclusion that the separates from soils of the <u>same geologic origin are not alike in their chemical composition</u>.

SUMMARY

1. Previous investigators have noted the unequal distribution of the plant food elements among the sand, silt, and clay separates of the soil.
2. In the case of phosphorus, the larger amounts are found in the clay and the sand, due, in the former case, to the organic matter, soluble salts, and the precipitated phosphates of iron and aluminum, and in the latter case to inclusions of phosphatic minerals in the large sand grains. These inclusions are most likely to be found in soils in a rather unweathered condition. The fine sand and the silt are low in phosphorus.
3. Attempts to calculate the per cent of phosphorus from the mechanical analysis, using the phosphorus value for each fraction reported in the data, give a fair approximation to the determined value in the case of the sands, but the deviations are not uniform and make the method unreliable. In the case of the sandy loams, the deviation is still greater.
4. Although the soils studied were virgin soils and as uniform as they could be with respect to source of material and method of formation, they showed no inclination to have a constant definite relationship between the textural composition and the phosphorus content. Since this is true, it is hardly possible that soils under cultivation or soils of different geologic origin could possess such a relationship. The work of the Bureau of Soils, reported in Bulletin No. 54, confirms this.
5. A study of the distribution of potassium, calcium, and magnesium in the soil separates might show a more constant rela-

tionship, for these elements occur in the more abundant minerals, whereas phosphorus is found in accessory minerals, in the form of organic matter, and as the precipitated iron and aluminum phosphates.

Approved Guy W. Conrey

Soils