SELECTION OF EFFICIENT METHODS FOR SOIL SAMPLING

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INTRODUCTION

Since the purpose of any soil survey is to characterize the area as fairly as possible within the limitations of the number of samples that it is possible to take and analyze, the efficiency of the sampling plan adopted is a major concern. Soil sampling procedure may be divided into two parts: first, the allocation of the samples over the region under survey, and second, the technique of sampling. The details of sampling, in particular the description of the various horizons, have been worked out with care (2, 4). Various considerations such as the slope and other pertinent physical features of the terrain, as well as the cover crops, have also been stressed (5, 8, 9, 10). The need for taking replicate samples is well recognized (5, 7). There appears to be a lack of quantitative information regarding the disposition of the replicate samples. In order to secure data to test the adequacy of various sampling plans, two soil types were studied using a sampling pattern that would bring out the relative agreement of duplicate samples separated by predetermined distances.

The classification of soils presupposes that the distinguishing characteristics of any given type are fairly constant. The range of variation of any particular characteristic for a soil type is, in general, obscured by local variations due to incidental conditions that may exist and which are often unknown to the surveyor. Thus, for example, two areas separated by some miles may have average values for pH (determined by taking a great many samples) that differ by only two- or three-tenths. Individual samples within each area may show a far greater variation. Consequently, if but one sample is taken from each of these widely separated areas, the difference in pH between the samples reflects not only the real difference in acidity between the two areas but also the local conditions which may have been encountered. The sampling procedure adopted in this work permits the separation of these two factors and enables the investigator to determine the real range of variation of the soil character. Furthermore, it is possible to devise sampling schemes which will indicate whether differences found between separated areas are of a magnitude found naturally in the soil type or are so large as to constitute evidence that the soil has been altered as a result of exposure to contamination on a large scale.

REGIONS SURVEYED

Care was taken to select regions that would be as free as possible from complicating factors. This required that the sites be at a considerable dis-

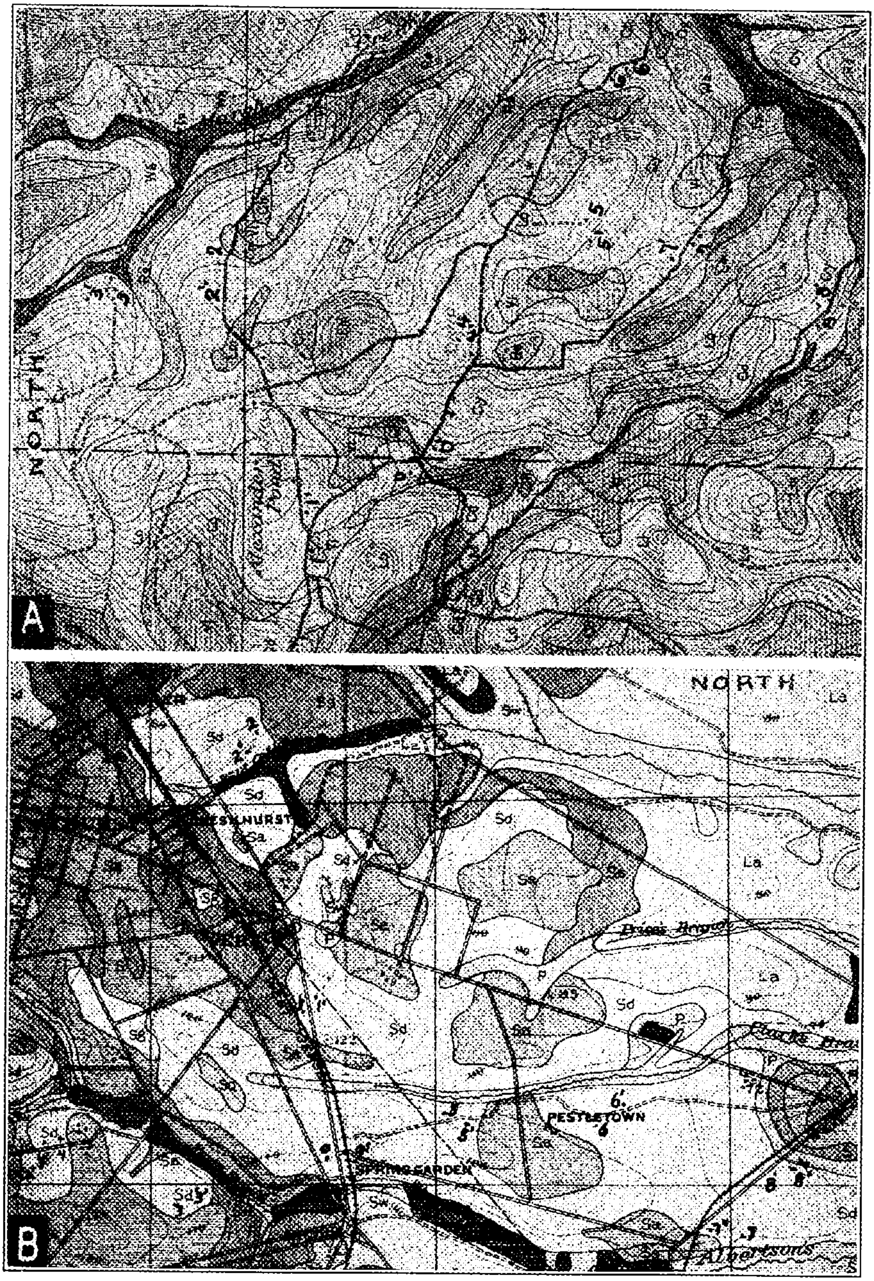

FIGURE 1. A. Section of soil survey map of Broome County, New York (6). B. Section of soil survey map of the Camden area, New Jersey (1) showing location of the places sampled. Scale 1 inch equals 1.3 miles.

tance from manufacturing centers. A region not under intensive cultivation was sought because of the manifest difficulty in securing samples in tilled areas which would not reflect the results of agricultural operations. It was also essential that recent soil survey maps be available as a guide in determining the soil type.

Figure 1 A shows a reproduction of portion (Lat. 42° 05′, Long. 75° 32′) of the soil survey map for Broome County, New York (6). In this section the predominating soil is Culvers gravelly silt loam (Cy). The soil here is a dark-brown, friable, slightly gritty, silt loam to a depth of six or eight inches. Below this depth increased compactness and larger stones are encountered. It was found that a considerable portion had been set aside as a wild life sanctuary and that most of the remainder was not under cultivation. Furthermore a preliminary survey showed a marked uniformity in the cover crop of native grasses. Wild strawberries were invariably present at the sampling points. The samples were collected June 22, 1937.

The other area (Lat. 39° 42′, Long. 74° 50′) surveyed on July 30, 1937 is shown in Figure 1 B which is copied from the soil survey of the Camden area, New Jersey (1). The prevailing soil here is Sassafras loamy coarse sand (Sd). It is described in the soil survey (1, p. 13) as consisting "of brown, grayish-brown, or yellowish-brown loamy coarse sand about eight inches thick. This rests on reddish-yellow or yellowish-red coarse loamy sand, which in most places extends to a depth greater than three feet." This soil type in the area surveyed was not under cultivation. The cover varied from conifers to scrub oak, both being commonly present. Blueberries were always found in the areas sampled.

SAMPLING PROCEDURE

The same procedure of sampling was followed with both soil types. In each case nine stations were sampled with approximately one mile between adjacent stations. At each station two substations were selected one thousand feet apart. Two sampling areas one hundred feet apart were located at each substation. Finally, in each sampling area two sample points were taken ten feet apart. These distances were not adhered to rigidly and this combined with complete freedom as to direction permitted the exercise of the utmost discrimination in securing the samples under comparable conditions. At each sampling point three layers of soil were collected. These were, in the case of the Culvers soil, the top two inches, the two to six inch layer, and the top six inches or composite sample; and for the Sassafras the A_0, A, and B horizons. The A_0 horizon consisted of decomposed organic matter after removal of loose leaves and debris. The A horizon was sampled to the full depth, the B horizon to a depth of five inches.

The recording of samples was greatly facilitated by the adoption of a numbering system by which each sample was identified by a code number of three digits, *xyz*. The digit in the *x* position is either 0, 1, or 2 and these represent the top layer, lower layer, and the composite samples respectively for the Culvers loam, and the three horizons A_0, A, and B for the Sassafras sand. The nine stations were given the numbers 0 to 8 and these

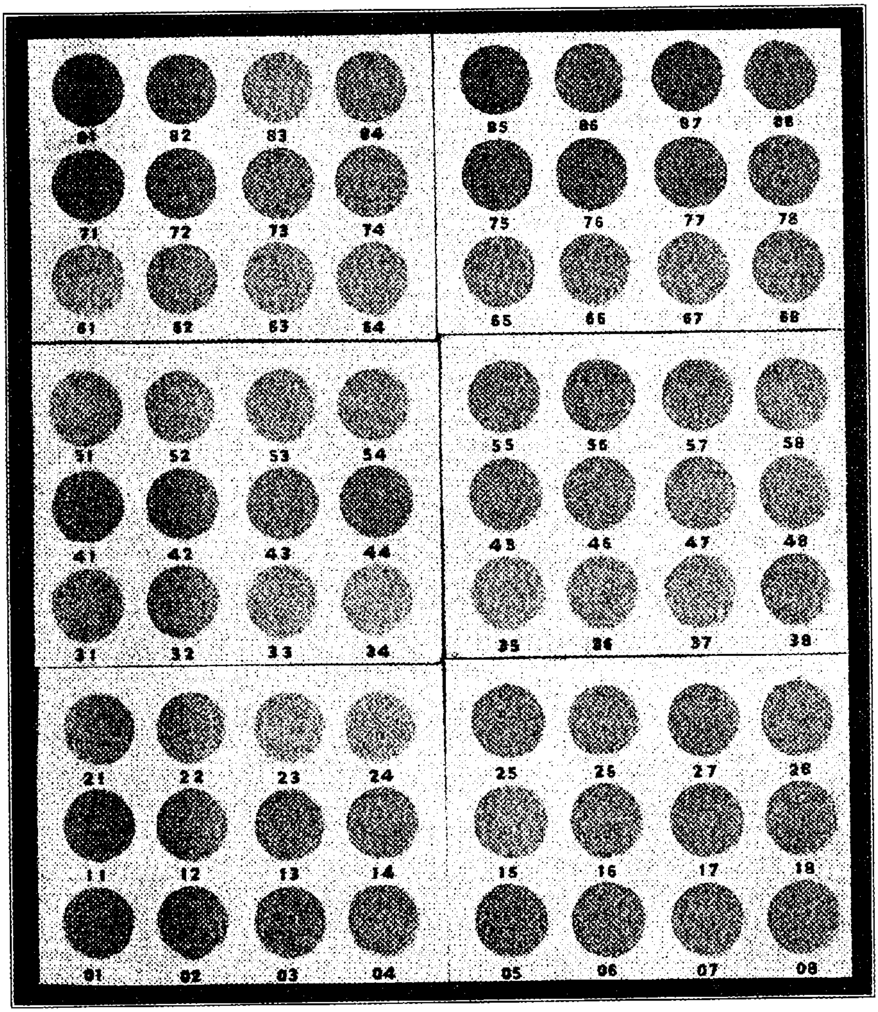

FIGURE 2. The 2–6 inch layer of Culvers gravelly silt loam displayed on spot plates. All the samples in a horizontal row are from the same station. Disposition of samples within station described in text.

appear in the *y* position in the code. The eight sample points comprising each station were numbered 1 to 8 and occupy the *z* position in the number.

On the maps are shown the locations of the two substations for each station. Sample points 1, 2, 3, and 4 make up one substation and 5, 6, 7, and 8 the other substation one thousand feet away which is marked with a prime. The same convention holds for all stations. It is readily seen that the samples at the extreme north of the Culvers area (substation 3′) were numbered as follows:

0–2 inch layer	035	036	037	038
2–6 " "	135	136	137	138
Composite	235	236	237	238

Samples ending in 5 and 6 are taken ten feet apart and are separated by one hundred feet from those ending in 7 and 8 which are in turn ten feet apart. Samples ending in 1, 2, 3, and 4 follow the same pattern.

LABORATORY EXAMINATION OF SAMPLES

The appearance of these soil samples may be judged from Figure 2. Figure 2 shows a photograph of the 72 samples of the two to six inch layer

TABLE I

pH VALUES FOR THE 72 SAMPLES OF CULVERS GRAVELLY SILT LOAM

Station number		Sample number								Station average
		1	2	3	4	5	6	7	8	
0	Surface layer	5.16	5.06	5.55	5.48	4.86	4.86	5.04	4.96	5.12
1		5.23	5.01	5.57	5.30	5.37	5.11	5.08	4.99	5.21
2		5.28	5.08	5.01	5.13	5.45	5.53	5.45	5.53	5.31
3		5.01	4.89	5.15	5.01	4.72	4.89	4.87	4.72	4.91
4		4.52	4.49	4.62	4.35	4.91	4.89	4.71	4.82	4.66
5		4.28	4.25	4.38	4.59	4.62	4.76	4.86	4.81	4.57
6		4.77	4.77	4.93	4.91	4.74	4.87	4.84	4.76	4.82
7		4.79	4.59	4.82	4.72	5.01	4.71	4.77	5.04	4.81
8		4.96	5.11	4.87	4.43	4.94	4.55	4.49	4.64	4.75
									Av.	4.91
0	2″–6″ layer	5.21	5.18	5.31	5.37	4.84	4.81	4.87	4.87	5.06
1		5.13	4.99	5.30	5.16	5.28	5.18	5.04	5.08	5.15
2		5.25	5.11	5.08	5.09	5.15	5.16	5.20	5.28	5.17
3		4.86	4.84	4.93	4.87	4.84	4.82	4.86	4.84	4.86
4		4.52	4.60	4.60	4.37	4.91	5.11	4.77	4.86	4.73
5		4.40	4.45	4.65	4.93	4.71	4.79	5.15	4.84	4.75
6		4.87	4.69	4.94	4.89	4.72	4.71	4.86	4.81	4.82
7		4.82	4.55	4.67	4.74	5.01	4.82	4.60	4.84	4.76
8		5.13	5.09	4.69	4.60	4.81	4.32	4.54	4.64	4.73
									Av.	4.89
0	Composite	5.18	5.16	5.20	5.26	4.77	4.74	4.81	4.86	5.00
1		5.09	4.87	5.28	5.09	5.20	5.08	5.04	4.98	5.09
2		5.20	5.08	5.04	5.01	5.28	5.30	5.25	5.40	5.20
3		4.89	4.81	5.11	4.86	4.69	4.76	4.79	4.79	4.84
4		4.49	4.49	4.57	4.37	4.84	4.87	4.71	4.79	4.65
5		4.30	4.35	4.45	4.69	4.59	4.69	4.98	4.71	4.60
6		4.74	4.64	4.86	4.82	4.59	4.84	4.87	4.72	4.77
7		4.82	4.45	4.69	4.74	4.87	4.72	4.69	4.91	4.74
8		4.99	5.09	4.77	4.54	4.89	4.43	4.40	4.49	4.71
									Av.	4.84

of Culvers loam arranged on porcelain spot plates. The numbers identify the station and sample number. Although the colors are not reproduced the different shades show something of the color range exhibited by the soils. This device affords an excellent means of comparing a large number of soil samples as regards their physical appearance.

TABLE II

pH VALUES FOR THE 72 SAMPLES OF SASSAFRAS LOAMY COARSE SAND

Layer	Station number	Sample number 1	2	3	4	5	6	7	8	Station average
Surface layer	0	4.21	4.16	4.32	4.23	4.08	4.20	3.94	4.57	4.21
	1	4.40	4.47	4.40	3.98	4.06	3.53	4.15	3.76	4.09
	2	3.93	3.57	3.64	4.20	4.23	4.94	3.83	3.93	4.03
	3	3.89	3.96	4.13	4.01	3.89	3.83	3.74	3.62	3.88
	4	3.86	3.88	3.98	3.74	4.13	4.27	4.16	4.03	4.01
	5	3.89	3.86	3.39	3.54	3.69	3.52	4.01	4.15	3.76
	6	4.21	3.91	3.94	4.16	3.81	3.79	3.84	3.50	3.90
	7	3.57	4.33	4.11	3.71	3.74	3.67	3.94	3.81	3.86
	8	3.56	3.57	3.69	3.56	4.05	3.74	3.72	3.69	3.70
									Av.	3.94
A horizon	0	4.45	4.38	4.43	4.54	4.47	4.54	4.62	4.52	4.49
	1	4.50	4.49	4.35	4.28	4.20	4.26	4.40	4.13	4.33
	2	4.11	3.68	4.21	4.16	4.33	4.65	4.20	4.67	4.25
	3	4.23	4.38	4.55	4.55	4.47	3.88	3.88	3.94	4.24
	4	4.06	4.10	4.35	4.18	4.67	4.86	4.43	4.64	4.41
	5	4.20	4.18	3.89	3.96	4.06	3.95	4.43	4.35	4.13
	6	4.64	4.55	4.64	4.55	4.20	4.06	4.21	3.96	4.35
	7	4.32	4.51	4.32	4.23	4.23	4.38	4.30	4.40	4.34
	8	3.93	4.21	3.91	3.96	4.47	4.43	4.47	4.01	4.17
									Av.	4.30
B horizon	0	4.77	4.74	4.99	4.84	4.71	4.69	4.72	5.18	4.83
	1	4.67	4.45	4.64	4.65	4.71	4.30	4.52	4.49	4.55
	2	4.74	4.54	4.67	4.67	4.82	4.91	4.67	4.84	4.73
	3	4.74	4.59	4.77	4.60	4.59	4.60	4.38	4.55	4.60
	4	4.40	4.47	4.62	4.57	4.93	4.89	4.74	4.57	4.65
	5	4.42	4.81	4.60	4.49	4.64	4.59	4.93	4.69	4.65
	6	5.30	5.08	4.72	4.49	4.60	4.69	4.62	4.64	4.77
	7	4.67	4.67	4.65	4.71	4.67	4.62	4.67	4.69	4.67
	8	4.50	4.49	4.33	4.35	4.49	4.49	4.65	4.49	4.47
									Av.	4.66

The acidity is only one of many soil properties but its ease of measurement was an advantage in obtaining information regarding sampling methods. The acidity was determined by means of a Leeds and Northrup glass electrode. In each day's run one complete set of 72 samples all from the same horizon were measured. The measurements were repeated for one set and the standard deviation of a single measurement found to be 0.05 pH unit. The soil suspensions were prepared by stirring together 50 cc. of water and 20 grams of soil, which had been air-dried and put through a 10 mesh sieve. The mixture was stirred occasionally during an interval of 30 minutes before determining the acidity.

The complete list of pH values for the Culvers loam is given in Table I and for the Sassafras sand in Table II together with the mean values for the various stations. Each table is divided into thirds corresponding to the three layers sampled. The eight values in any row are from the same station, in accordance with the numbering scheme described above. The immediate impression given by the data is that the averages of the several stations for any set agree more closely than individual samples from the

TABLE III

DIFFERENCE IN pH OF DUPLICATE SAMPLES OF CULVERS GRAVELLY SILT LOAM

Distance between duplicate samples	0–2 inch layer		2–6 inch layer	
	Av. diff.	Max. diff.	Av. diff.	Max. diff.
10 feet	0.14	0.44	0.11	0.49
100 feet	0.18	0.84	0.20	0.53
1000 feet	0.26	0.69	0.25	0.81
1–3 miles	0.36	1.32	0.28	1.05

TABLE IV

DIFFERENCE IN pH OF DUPLICATE SAMPLES OF SASSAFRAS LOAMY COARSE SAND

Distance between duplicate samples	A_0 horizon		A horizon		B horizon	
	Av. diff.	Max. diff.	Av. diff.	Max. diff.	Av. diff.	Max. diff.
10 feet	0.23	0.76	0.17	0.59	0.13	0.46
100 feet	0.27	1.11	0.19	0.59	0.18	0.81
1000 feet	0.31	1.37	0.28	0.99	0.19	0.70
1–3 miles	0.35	1.55	0.28	1.18	0.20	1.00

same station, although samples separated by but ten feet show very good agreement. The average difference between samples separated by 10 feet, 100 feet, 1000 feet, and by stations were calculated from the data and are listed in Tables III and IV. The maximum differences encountered are also listed. The average differences become larger as the distance between the duplicate samples increases. In the case of the lower layers the average difference is evidently approaching a limiting value. This is shown in Figure 3 which brings out the greater variability of the surface layers in comparison with the lower layers. The differences do not arise to any important extent from the error of analysis, since the correction for this source amounts to less than 0.02 pH unit.

STATISTICAL ANALYSIS OF DATA

An elegant analysis of these data is furnished by the partition of the variance into several categories. This is given in detail for the surface layer of the Culvers loam in Table V. The *z* distribution (3, p. 248) shows that statistical significance may be attached to the differences in variation, i.e., the mean squares, calculated for the several items. The data may be con-

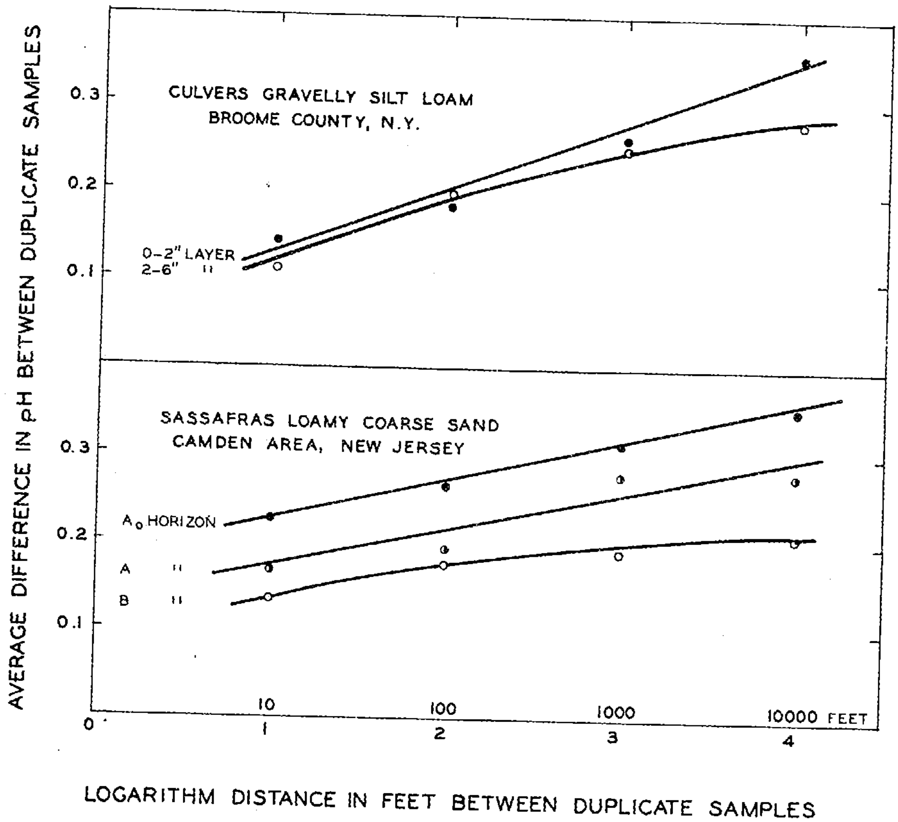

FIGURE 3. Graph showing the relative variability of the various soil layers. The average difference between duplicate samples becomes larger as the linear distance between the samples increases. The curves show that this difference approaches a maximum value for the lower layers.

sidered as 36 pairs of duplicate samples (ten feet apart) and Student's method used. The mean square in that case will be twice as large as that given for sample points in Table V. This is the case because Student's method gives the variance of the difference between two samples while the value in the table is the variance of a single sample. The values for each pair of sample points may be combined giving 36 items which may be arranged in 18 pairs of neighboring sample areas. Student's method may be applied to these values in turn, and the result compared with the entry after sample areas.

TABLE V

ANALYSIS OF VARIANCE OF THE SURFACE LAYER OF CULVERS GRAVELLY SILT LOAM

Item	Degrees freedom	Sum of squares	Mean square	Standard deviation
Between sample points	36	0.5758	0.01599	0.126
Between sample areas	18	0.6536	0.03631	
Between substations	9	1.3393	0.1488	
Between stations	8	4.0984	0.5123	
Total	71	6.6671		

The mean squares for the other five sets are tabulated in Table VI. In only one instance, the A horizon of Sassafras sand, does the mean square fail to increase as the distance increased between places contrasted. The mean squares for substations and stations in this column do not differ significantly.

TABLE VI

MEAN SQUARES FROM ANALYSIS OF VARIANCE

Variance between	Culvers loam		Sassafras sand		
	2–6″ layer	Composite	A_0 horizon	A horizon	B horizon
Sample points	0.01176	0.01391	0.04618	0.02225	0.01409
Sample areas	0.03471	0.02494	0.06546	0.03621	0.03519
Substations	0.11432	0.11856	0.15019	0.21380	0.04982
Stations	0.2724	0.3441	0.21586	0.10684	0.09536

Following a procedure given in detail by Tippett (11, p. 92, 93) the estimated variance for the different items has been calculated. These are as follows for Culvers gravelly silt loam:

	0–2 inch layer	*2–6 inch layer*
Sample points	0.01599	0.01176
Sample areas	0.0101	0.0115
Substations	0.0281	0.0199
Stations	0.0454	0.0198

From these may be calculated the variance of the station mean of eight samples. First two sample points are averaged, the result having a variance of 0.01599/2, or 0.0080. This is added to 0.0101 to give the variance for a sample area as sampled, or 0.0181. Two of these constitute a substation so that a substation as sampled has a variance of 0.0181/2+0.0281, or 0.0372. The value of 0.0640 is obtained for the station variance in the same way.

This checks the value taken from Table V since the variance of a station mean is one-eighth of 0.5123, or 0.0640.

The values are now in hand to compute the variance of station means when sampled according to some other pattern. Thus if but four samples are taken at intervals of 1000 feet the variance is

$$\frac{0.0160+0.0101+0.0281}{4}+0.0454=0.0590$$

or less than that obtained with eight samples most of which are taken in close proximity to each other. Any other combination of distances may be assumed and the efficiency of the arrangement determined.

DISCUSSION

The usefulness of laboratory examination of soil samples in the classification of soil types depends on the selection for study of soil properties which vary over a limited range within the type and which take on uniquely different values for different types. The range within which a given property may vary for each type may be determined by choosing a number of localities all classified as the same type and sampling very intensively by taking a great number of samples. The local irregularities will disappear in the station averages which may then be used to estimate the range over which the property varies. This is equivalent to making the first term in the computation in the preceding paragraph approach zero since the denominator represents the number of samples taken. The remaining quantity, 0.0454, which characterizes the station variance may be doubled to give the variance of the difference between two stations. The standard deviation is the square root of this quantity, or 0.30, and when divided by 1.253 gives the average difference, or 0.24. Differences up to two and one-half times the average difference will be frequently encountered so that the range within which the great bulk of the stations will fall is 0.6 pH unit. The maximum difference found between any pair of the nine station means, even with limited sampling, is 0.74. Similar calculations for the lower layer give an expected range of about 0.4 pH unit. The maximum observed difference between station means is 0.44. In the instance of the two soil types under consideration there is a marked difference in the average values for the acidity.

The problem, referred to in the introduction, of distinguishing whether differences in properties found between widely separated areas are such as occur naturally in the type or are indicative of the superimposition of unusual conditions, also requires a knowledge of the variation found within the type. In some cases soils have been exposed to industrial waste gases, such as sulphur dioxide, and it becomes important to ascertain whether the soil has been damaged, and if so, the limits of the area affected. It should be clear that supposed differences in properties must be considered in view of the distances involved. Certainly the evaluation of such differences in terms of the agreement of samples taken within a limited area courts misinterpretation.

A recent article by Walker (12) discusses the general question of heterogeneity within a soil type and its bearing on field experiments. This author strongly advocates the use of statistical control in soils experiments. Soil studies are often carried on simultaneously with yield trials. The sampling methods used in the soil work may properly be given the same consideration that is now directed to the design and analysis of the yield trials.

The evidence in this work indicates that the sampling of large areas may have been inefficient because the replicates were taken too near to each other. This may be demonstrated by eliminating all the even or all the odd numbered samples in Tables I and II and noting that the stations are nearly as well defined by the remaining values. Samples taken close together too often show the influence of the same local situation and contribute little more than one sample would to the formulation of an accurate estimate of the whole area. When the samples are more widely dispersed there is far greater opportunity for the transient conditions to neutralize themselves rather than perpetuate themselves in the average for the area.

SUMMARY

Culvers gravelly silt loam from Broome County, New York, and Sassafras loamy coarse sand from the Camden area, New Jersey, were sampled at nine stations scattered over an area of several square miles. At each station samples were collected at definite intervals and the acidity of the samples determined. The results show in each case that samples from widely separated points vary more than samples taken close together. This was also observed to hold for the lower horizons where the variation was not as great and tended to reach a maximum value characteristic of the soil type.

The data were subjected to statistical analysis to show the relative efficiency of various spacings for replicate samples when large areas are surveyed. It was found that intervals as low as 10 feet, or 100 feet, were too small to constitute an effective method for sampling these areas.

The sampling procedure was discussed with reference to its application in crop fertility studies, soil classification, and the investigation of possible damage to soils over large areas.

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