Heterogeneity of Soil of Agricultural Land in Relation to Soil Sampling

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The heterogeneity of soil fertility in apparently uniform, agricultural lands was studied. One-hundred composite soil samples were taken from four New Jersey farms. Their available N, P, K, and Mg were determined, and statistical analysis was employed. The coefficient of variability of various available nutrients ranged from 10 to 53%. The findings indicate that the heterogeneity of soil fertility of agricultural soils is far beyond that commonly anticipated. Optimum sample sizes for various nutrients calculated from the data raised a question as to the validity of the present, generally accepted methods of soil sampling. New approaches should therefore be taken to meet the ever-changing soil fertility levels due to modern farming practices, especially intensive use of concentrated chemicals. Further investigation in this direction appears to be urgently needed.

Soil has been considered as a heterogeneous body, a mixture of organic and inorganic materials. Naturally, the composition of soils varies from location to location and from site to site (*1*, *2*, *5*, *7*). However, to a certain extent, soil can also be considered as a homogenous body, in a physical sense, within a limited area (*1*, *2*). For these reasons, the knowledge of sampling has been recognized as one of the most important keys to soil tests. The validity of soil analysis depends on the fairness of samples as well as the technique employed in studying the samples.

Tisdale and Nelson (*9*) recommend that each composite sample should consist of borings from 15 to 20 locations over an average field of 10 acres. Graham (*2*) suggests that a final sample consisting of 5 to 10 of the composites of cores per 40 acres would give quite sufficient and accurate information in that field for most soil management practices.

The purpose of taking composite samples is to attempt to minimize the influence of nonuniformity of a given soil. Tisdale and Nelson (*9*), however, point out that the composite sample which is approximately equivalent to a pound from an average field of 10 acres (1 pound per 20,000,000 pounds of surface soil at plow depth) is usually extremely small and would likely cause considerable error. But for labor and time saving, a practical operation must be adapted.

The inherent soil fertility of virgin soils, as a rule, is less heterogeneous than the soil fertility of farmed lands where various agricultural activities such as liming, manuring, and fertilization have been conducted. This study reveals that the soil sampling methods widely used at present require further critical tests.

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Materials and Methods

Four apparently uniform lands about 10 miles apart were selected from New Jersey farms (*4*) which had been cultivated since the early settlement of the area. The crops of the year before soil sampling were: oats-red clover mixture, corn, corn, and sod for the College farm, Forsgate farm, A. Pinter farm, and E. Pinter farm, respectively. An area of 60 × 250 feet was chosen from each of the farms and subdivided into 25 plots of 12 × 50 feet. Soil samples were taken from the plots at a depth of about 7 inches with a Hoffer soil-sampling tube. Each composite sample from a plot consisted of 12 borings from different sites selected at random. Soil samples were air dried and mixed well to eliminate possible errors which may arise from subsampling. The soils were passed through a 2-mm. sieve and analyzed for their available P_2O_5, K_2O, and Mg content with the methods described by Hanna and Purvis (*3*). The soils passed through a 1-mm. screen were tested for their potentially available nitrogen by the procedure of Purvis and Leo (*4*, *6*). Statistical analyses of data were employed (*8*). The optimum number of randomly selected samples assumed with a precision level of the sample-mean within $P = 5\%$ were calculated from the coefficients of variation at the 0.10, 0.05, and 0.01 levels of significance.

Results and Discussion

Distributions of the available nutrients in the soils from the four New Jersey farms are shown semidiagrammatically in Tables I to IV.

Nitrogen contents ranged from 62 pounds per acre at the Forsgate farm to 155 pounds per acre at the A. Pinter farm; P_2O_5, from 1 pound per acre at the E. Pinter farm to 244 pounds per acre at the Forsgate farm; K_2O, from 35 pounds per acre at the A. Pinter farm to 600 pounds per acre at the Forsgate farm; Mg, from 15 pounds per acre at the E. Pinter farm to 180 pounds per acre at both the Forsgate and A. Pinter farms. There were definite differences in soil fertility among the various farms.

Table V shows the means, standard deviations, standard errors of means, calculated *t*-values, and coefficient of variation of the available nutrients from each of the four New Jersey soils. The standard deviations of all nutrients of the soils were beyond the confidence limits of significance at the 1% level, and the variability of the nutrients in soils was remarkably great. As a whole, N tests showed the least variation, Mg the greatest, with K_2O and P_2O_5 in between according to the order as listed. McKenzie (*5*) found that all nutrients in a soil tend to rise and fall together in virgin soils. Since there is no such tendency in the farmed soils studied here, it would be reasonable to assume that agricultural activities, such as intensive use of chemical amendments, have drastically changed the nutrient status of the soils.

In this experiment, as mentioned previously, one composite sample of 12 borings was taken from each plot of 12 × 50 sq. ft. (or 1/72.6 acre), i.e., about 1 pound of soil sample from 27,550 pounds of surface soil. In comparison with the amounts of soils recommended by Tisdale and Nelson (*9*) and by Graham (*2*), i.e., 1 pound from 20 million pounds and from 80 million pounds, respectively, the size of the

Table I. Distribution of Available Nutrients in Soil in the College Farm

(Values in pounds per acre)

N.....	122	100	111	117	99
P_2O_5...	6	5	5	7	8
K_2O...	80	75	90	95	65
Mg....	40	45	40	50	40
N.....	124	96	101	108	101
P_2O_5...	6	4	9	9	12
K_2O...	80	80	110	100	90
Mg....	40	45	75	45	45
N.....	124	132	119	100	104
P_2O_5...	9	11	9	8	23
K_2O...	110	125	110	85	140
Mg....	90	45	40	100	100
N.....	95	120	110	95	99
P_2O_5...	9	9	10	9	7
K_2O...	120	90	90	100	75
Mg....	60	75	60	35	30
N.....	106	138	105	92	106
P_2O_5...	5	5	6	5	8
K_2O...	135	100	100	130	125
Mg....	30	30	30	30	30

12 ft. 50 ft.

Table II. Distribution of Available Nutrients in Soil of the Forsgate Farm

(Values in pounds per acre)

N.....	82	83	87	83	94
P_2O_5...	108	104	88	100	104
K_2O...	450	500	560	500	400
Mg....	135	125	120	135	100
N.....	85	62	82	82	88
P_2O_5...	100	104	76	120	164
K_2O...	375	600	500	425	360
Mg....	135	180	150	180	135
N.....	78	77	71	73	94
P_2O_5...	148	136	120	128	224
K_2O...	560	560	500	400	540
Mg....	160	180	125	150	135
N.....	87	87	82	80	89
P_2O_5...	276	184	176	164	244
K_2O...	520	460	440	520	520
Mg....	180	135	180	150	180
N.....	82	83	87	83	74
P_2O_5...	116	116	136	156	180
K_2O...	420	320	480	540	400
Mg....	160	165	135	125	140

12 ft. 50 ft.

Table III. Distribution of Available Nutrients in Soil of the A. Pinter Farm

(Values in pounds per acre)

N.....	132	149	126	121	145
P_2O_5...	4	6	2	6	5
K_2O...	75	155	45	80	55
Mg....	180	180	180	180	110
N.....	109	120	155	111	113
P_2O_5...	2	4	5	5	5
K_2O...	85	165	70	65	90
Mg....	180	180	180	180	180
N.....	125	130	121	127	118
P_2O_5...	7	9	5	4	4
K_2O...	80	65	60	35	50
Mg....	180	180	180	180	135
N.....	141	117	118	117	129
P_2O_5...	7	7	5	5	3
K_2O...	40	125	75	90	55
Mg....	120	150	125	180	150
N.....	122	110	108	126	118
P_2O_5...	4	4	7	5	17
K_2O...	70	65	60	80	90
Mg....	180	180	120	90	180

12 ft. 50 ft.

Table IV. Distribution of Available Nutrients in Soil of the E. Pinter Farm

(Values in pounds per acre)

N.....	90	83	77	89	81
P_2O_5...	2	1	1	2	2
K_2O...	80	70	80	105	105
Mg....	25	30	30	30	30
N.....	96	93	90	81	88
P_2O_5...	2	1	2	2	1
K_2O...	55	65	65	105	95
Mg....	30	30	25	30	35
N.....	93	115	82	88	77
P_2O_5...	2	2	2	2	2
K_2O...	75	90	70	85	80
Mg....	40	35	30	25	25
N.....	85	83	99	108	101
P_2O_5...	2	2	2	2	2
K_2O...	60	55	95	90	70
Mg....	20	20	20	15	15
N.....	92	91	93	90	89
P_2O_5...	1	2	2	2	2
K_2O...	80	70	85	85	65
Mg....	15	20	20	20	15

12 ft. 50 ft.

sample used in this study should be considered more reliable with less error introduced by sampling. However, the statistical analysis indicates that there were still tremendous variations in various nutrients in the soils from different plots at each location.

A stratified sampling method is suggested for a land with inherent heterogeneity in soil fertility. However, it is neither practical nor possible to apply the method in most agricultural soils which exhibit apparent uniformity but actually are heterogeneous.

Table VI shows the calculated optimum sizes of sample which are required to satisfy the probability at the 0.10, 0.05, and 0.01 significance levels, respectively. The optimum size of sample for each nutrient varies significantly from location to location, suggesting that there is no definite pattern of optimum size of sample for various nutrients studied in any single location. For instance, should the 0.05 level of significance be considered, 336 samples should be taken from the College farm for a reliable P_2O_5 test, while only three samples would be enough from the same farm for a representative Mg test. These results also reveal that there is no definite pattern of an optimum size of sample for any one nutrient in various locations. For example, should the 0.01 level of significance be demanded, 1331 observations should be required for a N test at the Forsgate farm, and only 27 should be needed for both the A. Pinter and E. Pinter farms. It is, therefore, concluded that the optimum size of sample for various nutrients of the soils studied ranged from three to more than a thousand observations.

The results strongly suggest that the sampling methods currently used are far from being ideal for those agricultural lands similar to the ones studied here. The sampling sizes of the methods currently in use hardly approach the lowest extremes of the optimum sampling size calculated.

If a piece of land is fairly homogeneous in its available nutrients, as shown in the case of the E. Pinter farm where little

Table V. Statistical Analysis of Four Agricultural Soils in New Jersey

Available Soil Nutrients	Statistical Measure[a]	College Farm	Forsgate Farm	A. Pinter Farm	E. Pinter Farm
N	$\bar{X}$	108.96	79.00	124.32	90.16
	S	12.38	17.53	12.36	8.94
	$S_{\bar{x}}$	2.48[b]	3.51[b]	2.47[b]	1.79[b]
	t	43.94	22.51	50.33	50.37
	C	11.36	22.19	9.94	9.91
P_2O_5	$\bar{X}$	8.16	142.88	5.48	1.80
	S	3.74	49.79	2.89	0.41
	$S_{\bar{x}}$	0.75[b]	9.96[b]	9.58[b]	0.08[b]
	t	10.88	14.34	9.45	22.50
	C	45.81	34.85	52.73	22.67
K_2O	$\bar{X}$	100.00	474.00	77.00	79.20
	S	20.41	73.21	31.42	14.91
	$S_{\bar{x}}$	4.08[b]	14.64[b]	6.28[b]	2.98[b]
	t	24.50	32.38	12.26	26.58
	C	20.41	15.45	40.81	18.82
Mg	$\bar{X}$	50.00	147.80	162.40	25.20
	S	2.17	22.96	28.36	6.99
	$S_{\bar{x}}$	0.43[b]	4.59[b]	5.76[b]	1.40[b]
	t	116.27	32.20	28.64	18.00
	C	4.34	15.54	17.47	27.75

[a] $\bar{X}$, mean; S, standard deviation; $S_{\bar{x}}$, standard error of mean; C, coefficient of variation; t, calculated t — value. All units are in pounds per acre except C which is in percentage of the mean.
[b] Significant at the 0.01 level.

Table VI. Optimum Size[a] of Sample Calculated from Data of Four New Jersey Farms at the 0.1, 0.05, and 0.01 Levels

Available Soil Nutrients	Precision Level as Percent of Mean	College Farm	Forsgate Farm	A. Pinter Farm	E. Pinter Farm
N	0.10	15	569	11	11
	0.05	21	788	16	16
	0.01	35	1331	27	27
P_2O_5	0.10	243	140	321	6
	0.05	336	194	445	8
	0.01	567	328	752	14
K_2O	0.10	48	28	193	41
	0.05	67	38	266	57
	0.01	113	65	450	96
Mg	0.10	2	28	35	89
	0.05	3	39	49	123
	0.01	5	65	83	208

[a] Formula used to obtain optimum sampling sizes is:

$$t = \frac{p\bar{X}}{\frac{S}{\sqrt{n}}} \text{ or, } n = \frac{t^2S^2}{(p\bar{X})^2} = \frac{t^2C^2}{p^2}$$

where, n = size of a sample; t = t-values at the 0.1, 0.05, and 0.01 levels, respectively; C = coefficient of variation $\left(C = \frac{S}{\bar{X}}\right)$; and p = a precision level, e. g., 5% of the mean.

fertilizer was used in the previous years, the eight to 16 composite samples may be adequate for P_2O_5 and N tests. On the other hand, in a farmed land, such as the Forsgate farm, where fertilizers were heavily banded in rows for years, the variation of available nutrients would be expected to be high, and therefore the size of samples should be appropriately increased.

In view of progress made in chemical techniques for soil testing and increasingly extensive and intensive use of soil amendments on agricultural lands, further study on proper methods of soil sampling would appear to be urgently needed.

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