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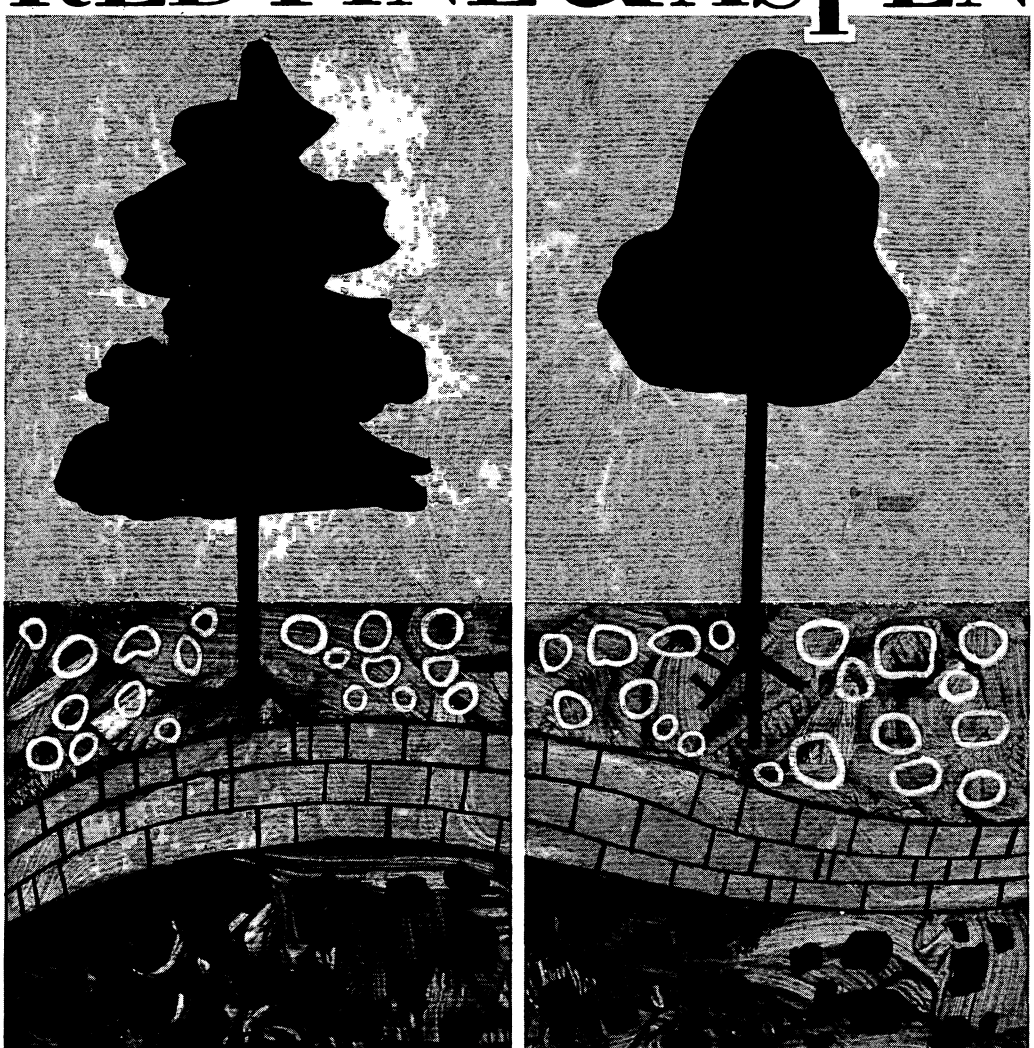
soil variation and sampling intensity under RED PINE & ASPEN in minnesota



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SOIL VARIATION AND SAMPLING INTENSITY UNDER RED PINE AND ASPEN IN MINNESOTA

David H. Alban

Many soil properties are extremely variable, even within small areas. Knowing the amount of this variation is necessary for accurate soil characterization and for better planning of studies to evaluate effects of land management on soils.

Agricultural soil variability has been studied to a limited extent, but little is known about variability of forest soils, and no data have been published on proper sampling intensity in northern Lake States forest soils. Some information on red pine (*Pinus resinosa* Ait.) plantation soil variability in the northeastern United States has been published (Mader 1963), but no such data are available for aspen (*Populus tremuloides* Michx.).

The main objective of this paper is to describe spatial soil variation so that the proper number of samples to collect can be determined. In addition, some information is presented on seasonal variation and laboratory analysis variation.

STUDY AREAS

Three red pine and three trembling aspen stands in northern Minnesota were sampled in July 1972. The red pine stands ranged in age from 49 to 72 years and the aspen 22 to 44 years. All stands were fully stocked (basal area = 90 to 200 ft^2/acre). The presence of charcoal in the forest floor of all stands but the lack of tree fire scars or scorched bark indicated past fires but no recent ones.

All stands are on level to gently sloping land with relatively uniform surface topography, typical of red pine and aspen sites in Minnesota. The soils developed from glacial till or outwash sands and include Chisholm, Hiwood, Faunce, Menahga, and Zimmerman soil series. The surface soil textures are loamy sand to sandy loam, and are generally finer in aspen than in red pine stands.

More detail about the soils and tree stands on the study areas are presented in the Appendix (table 2). The methods of field sampling and laboratory analysis are detailed in the Appendix, page 5.

RESULTS AND DISCUSSION

Soil Properties on Study Plots

The soils studied exhibit a wide range in some properties but a limited range in others (Appendix, table 2). For example, mineral soil pH and bulk density do not differ greatly from plot to plot, whereas many other properties commonly differ by a factor of three or more from one plot to another. Most soil properties are similar in both red pine and aspen stands, especially in the Hiwood soil series which supports both types. The greatest differences between species are in Ca and Mg content, both of which are higher under aspen in the forest floor and in two cases much higher in the 10 to 40 inch layer.

Most red pine and aspen stands we have examined in Minnesota occur on soils with characteristics which fall within the ranges reported in the Appendix, table 2. Therefore the number of samples to collect as recommended later in this paper are expected to be applicable to most red pine and aspen stands in Minnesota. Rocky, organic, or clay soils may be exceptions. But because no other information is available, the recommendations given may be used as rough guidelines for these kinds of soils. Sampling of these soils should be followed by statistical analysis (Appendix, page 5) to verify the applicability of the guidelines.

Number of Samples

The basic statistic used to compare variability of different soil properties is the coefficient of variation (*cv*) (Appendix, table 3). It is used to compute the number of samples needed to estimate the mean of a given soil property within specified limits of confidence. The method of calculating *n* is detailed in the Appendix, page 5.

Soil nutrients tend to be more variable than soil physical properties or pH. For example, in mineral soil, bulk density, pH, and sand content can be estimated with just a few samples, whereas other properties (particularly P, Ca, and Mg) require many more (Appendix, Fig. 1 and table 4). This corroborates results from both agricultural soils (Beckett and Webster 1971) and other forest soils (Ike and Clutter 1968, Metz et al. 1966).

For the soil properties examined there was no statistical difference in the mean number of samples needed between red pine and aspen, or between the two layers of mineral soil. Therefore for each property the number of samples needed to estimate the mean within 10 percent was calculated by averaging the numbers for both species and both soil layers (table 1). The properties break into four groups ranging in sample numbers needed from 2 for the least variable to 60 for the most variable. Soil P is by far the most variable soil property whether extracted by a weak reagent (0.01N HCl) or a stronger reagent (Bray's No. 1).

These numbers do not mean that to estimate soil P, for example, 60 samples must be collected and analyzed separately. The 60 collected soil samples could be composited into a single sample for laboratory analysis. But sometimes it may be desired to compare the means of a given soil property among several stands or in the same stand before and after some kind of treatment such as burning. Then samples should be randomly composited into a minimum of three samples for laboratory analysis. This will allow the precision of the estimated mean to be determined, and thus allow statistical comparison between means (Appendix, page 6).

The number of samples needed to estimate the mean of several forest floor properties within 10 percent were calculated for each of the six stands samples (table 1).

Table 1.—*Soil samples needed to estimate the mean of several soil properties*[1] *(the mineral soil values are applicable to both red pine and aspen stands and to surface soils as well as subsoils)*
(In numbers)

Soil property	Mineral soil: Average	Mineral soil: Proposed by groups	Forest floor[2] (average): Aspen	Forest floor[2] (average): Red pine
Bulk density	2		-	-
Sand	2	2	-	-
pH	2		2	2
Silt + clay	18		-	-
Nitrogen	18		11	33
ΔH_2O	26	25	-	-
Potassium	27		22	29
Calcium	41		25	50
Magnesium	41	40	17	32
Phosphorus (Bray 1)	60		23	39
Phosphorus (0.01N HCl)	61	60		
Ovendry weight	--	--	16	34
Ash	--	--	9	42

1/ Within 10 percent of the mean at the 95 percent confidence level. To estimate the number of samples needed to estimate means within limits other than ± 10 percent, multiply the *n* values by $\frac{100}{(\text{desired percent})^2}$. For example, to calculate the number of samples needed to estimate phosphorus ± 20 percent, multiply $60 \frac{100}{(20)^2} = 15$ samples.

2/ Forest floor nutrient analysis was for total amounts rather than for extractable forms.

Forest floor pH under either species can be estimated to ± 10 percent with only two samples whereas other properties require more intensive sampling. Most properties under red pine require 30 to 50 samples; only half as many are needed under aspen. This is in sharp contrast to mineral soil where species differences were minimal. Other unpublished studies in Minnesota have found average *cv's* for red pine forest floor weight to be 23 percent (50 stands) and for aspen 16 percent (15 stands), indicating that the species difference is real. Ovington (1954) found the forest floor to be unevenly distributed over the ground and, especially under conifers, to be thickest around tree boles. Pine needles, because of their shape, tend to disperse less than aspen leaves when they fall, and to be moved around less by wind after reaching the ground.

Like mineral soil samples, all forest floor samples can be composited into a single sample for analysis, or, if an estimate of the precision of the estimated mean is desired, the samples can be randomly composited into a minimum of three samples.

The time involved in digging even small soil pits prompted an examination of the use of soil sampling tubes. Small pits for sampling surface soils can be dug and sampled in 2 to 3 minutes each, but tube samples can be collected in 15 to 30 seconds each.

As a general guide, soil nutrients (except N) can be estimated adequately with about twice as many tube as pit samples (Appendix, table 5). For other, less variable properties, the number of tube samples should be the same as for pits.

Tube sampling, of course, cannot be effectively used in rocky soils or soils with dense root concentrations. Further, the kinds of tubes normally used for sampling (Jackson 1958) are not suitable for collecting bulk density samples, so this property must be determined separately.

Seasonal Variation

Soil properties vary not only spatially but may also vary seasonally. However, seasonal variation is nearly always much lower than spatial variation (Cameron et al. 1971). The large spatial variation usually obscures any seasonal effects even when intensive sampling is used (Ball and Williams 1968, Frankland et al. 1963).

The 3 red pine stands in which soil variability was measured were among 61 stands in Minnesota from which soil samples were collected. About one-third of the 61 stands were on the 5 soil series mentioned earlier. Nearly all of the others had soil properties that fell within the ranges reported in table 2 (Appendix). Each stand was sampled only once, but the sampling of the 61 stands extended throughout the growing season (June through October). The stands were sampled in a random manner such that each month was represented by stands scattered throughout the geographical range of the study. The average site index of the stands was not significantly related to the month of sampling, suggesting that stands sampled in each month represented the same population.

Statistical analysis (F tests of the means) showed that of all forest floor and mineral soil properties tested (pH, N, P, K, Ca, Mg, Silt + clay, and ΔH_2O), only pH was related to the month of sampling. And, although the seasonal effects on pH were significant, the actual differences were small. For example, in the 0 to 10 inch layer, samples collected from June through October had average monthly pH values of 5.64, 5.40, 5.51, 5.57, and 5.31. Soil pH varies less than most soil properties (Appendix, table 3), and this allows the detection of seasonal variation that for the other properties is masked by large spatial variation.

The small contribution of seasonal variability to the total variance, as indicated by our red pine data and the literature, means that sampling throughout the growing season will result in only small errors for the properties we examined. However, sampling should be completed before leaf fall in the autumn because major changes in the L horizon of the forest floor occur at this time.

Laboratory Analysis Variation

Laboratory analysis variation is usually a minor component of total soil variability (Jacob and Klute 1956), and if too large can usually be reduced by modifying the procedure or by running more duplicates. In the present study each analysis was run in duplicate or triplicate, allowing an estimate of laboratory variation. The *cv's* for all properties were less than 3 percent and for pH was only 0.5 percent, clearly showing that laboratory variation contributes little to total soil variation.

Size of Area

Large areas usually have greater soil variability than small areas of course, but the importance of area size may easily be overemphasized. In either mineral soil (Beckett and Webster 1971) or the forest floor (Frankland et al. 1963), a large part of the total variance occurs within a few meters. For many studies summarized by Beckett and Webster (1971), *cv's* rarely more than doubled from small plots (< than 0.02 acre) to large fields (200 acres). Thus, the results obtained in the present study (0.2 acre plots) could be utilized on typical forest management tracts (areas less than 40 acres) with little likelihood of serious error, if major differences in soil or vegetation types do not exist in the area.

SUMMARY AND CONCLUSIONS

Some soil properties are much more variable than others. In mineral soil, pH, bulk density, and sand content are relatively uniform whereas the soil nutrients are more variable. There is little difference in the variability of the mineral soil under aspen and under red pine, or in the variability of the surface and subsoil. Forest floor pH varies little. All other forest floor properties vary greatly, and about twice as many samples are required under red pine as under aspen to estimate the mean value with the same precision.

Estimating most soil nutrients required twice as many samples when using a cylindrical sampling tube instead of digging small soil pits. However, for the less variable soil properties (pH, particle size, and available water) sampling with tubes or pits required about the same number of samples.

Laboratory analysis variation is a minor component of the total soil variance. Similarly, seasonal changes in the soil properties measured are minor and much less important than spatial variation. This means that samples can be collected throughout the growing season without introducing major sources of error.

The results presented are directly applicable to small plots (0.2 acre), but literature reports suggest that the results can be extended to areas of 40 acres with little likelihood of serious error.

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APPENDIX

Methodology

Field Sampling

In each of three red pine and three aspen stands intensive soil sampling was done on a single 0.2 acre plot. Soil sampling points were located systematically from the plot center along the cardinal directions. If a sampling point occcured on a fallen log or directly beneath a tree bole, the point was moved 6 feet to the north. A detailed review of soil sampling methods and rationale is given by Petersen and Calvin (1965).

On each of the three red pine plots ten 1-foot square samples of the forest floor were collected and 10 soil pits dug directly beneath the sampled forest floor. A single sample was collected from each pit from the 0 to 10 inch layer and another from the 10 to 40 inch layer. About 1 quart of soil was removed for analysis from each layer; the sample was collected from throughout the layer and from all four sides of the pit. The three aspen plots were sampled similarly except that six forest floor and six soil pits were sampled per plot.

Soil bulk density (*Db*) was measured from only two pits per plot because of expected low variability. From each pit three bulk density samples were taken (by the core method: core volume = 140 cm^3) from the 0 to 10 inch layer and three from the 10 to 40 inch layer.

The 0 to 10 inch layer was also sampled on each plot using a 1-inch diameter cylindrical sampling tube in order to compare the variation of sampling by tubes with that by soil pits. On each plot 10 systematically located tube samples, each consisting of a single core from the sampler, were collected.

Laboratory Analysis

Forest floor samples were dried at 70° C and ground to pass a 20-mesh screen. Separate aliquots of the ground samples were: (1) analyzed for nitrogen by the Kjeldahl method, and (2) ashed at 525° C and the ash dissolved in dilute HCl. Calcium, Mg, and K were determined in the dissolved ash by atomic absorption spectroscopy. Phosphorus was determined colorimetrically.

Mineral soil samples were air dried, sieved through a 2 mm screen and the less than 2 mm material used for subsequent analysis. The material greater than 2 mm comprised less than 4 percent of the total sample weight. Nitrogen was determined by the Kjeldahl method. Calcium, Mg, and K were extracted with 1N NH_4OAc and determined by atomic absorption. Phosphorus was extracted with 0.01N HCl (Alban 1972) and Bray's No. 1 reagent (Bray and Kurtz 1945) and determined colorimetrically. Particle size analysis was done by hydrometer, and available water (Δ H_2O) was estimated from sieved samples as the difference between water held at 0.1 and 15 bars in standard moisture tension apparatus.

Standard statistical techniques were used to derive coefficients of variation (*cv*) for each property and to compute the number of samples needed to adequately predict the mean of each property.

Calculation of Number of Samples

The number of samples needed to estimate the mean of a soil property is calculated from the following formula:

$$n=\frac{t^2(CV)^2}{E^2},$$

where: n = The number of soil samples to collect.

CV = Coefficient of variation. A measure of the variation in the sample.

E = A specified error as percent of the mean. Most often is soils work the error is specified as 10 percent of the mean.

t = A statistic dependent on the number of samples and on the desired level of confidence. In soils we generally work at the 95 percent confidence level and at this level t values are as follows:

Samples (No.)	t *value*
3	4.3
5	2.8
10	2.2
15	2.1
20	2.1

Beyond 20 samples t stays constant at about 2. For most soil sampling problems we can assume t=2.0 with only minor errors introduced.

Example.—To calculate the number of samples needed to estimate the mean of soil K within 10 percent at the 95 percent confidence level for the 0 to 10 inch soil layer:

CV=0.19 Appendix table 2
E=0.10 Specified error
t=2.0 Assumed value

$$=\frac{(2.0)^2(0.19)^2}{(0.10)^2}=14 \text{ samples.}$$

Calculation of the Precision of the Mean

Assume that 60 soil samples have been collected from the 0 to 10 inch layer in a red pine stand as recommended in table 1 in order to estimate soil P. The samples were randomly composited into three samples for laboratory analysis which resulted in soil P values of 105, 110, and 115 pounds per acre, or an average soil P value of 110 pounds per acre. To estimate the precision of the mean use the following equation:

Mean soil P value ± (t) (standard error)

where: t=4.3 (with n=3, and at the 95 percent confidence level)

$$\text{standard error}=\frac{\sqrt{\dfrac{\Sigma\,(x-\bar{x})^2}{n-1}}}{\sqrt{n}}$$

$$=\frac{\sqrt{\dfrac{(105-110)^2+(110-110)^2+(115-110)^2}{3-1}}}{\sqrt{3}}$$

$$= 2.88,$$

therefore
soil P=110$\pm$(4.3)(2.88) or
110$\pm$12 pounds per acre.

Table 2.--*Stand, site, and soil characteristics for three red pine and three trembling aspen stands in Minnesota*

Species and soil series	Age	SI	pH	N	P	K	Ca	Mg	Oven-dry weight	Ash	Bulk density	Clay	Silt	Sand	ΔH_2O
	Yr.	*Ft.*		*lb/acre*					*1,000 lb/acre*	*Percent*	*g/cm^3*	*Percent*			
FOREST FLOOR															
Red pine															
Menahga	49	60	4.7	396	36	54	320	45	45	43					
Zimmerman	50	57	4.3	267	22	30	146	24	27	27					
Hiwood	72	57	4.5	421	38	54	340	54	54	40					
Aspen															
Hiwood	40	71	5.4	546	19	50	583	74	62	61					
Chisholm	22	80	5.2	691	26	77	717	77	64	53					
Faunce	44	64	6.0	616	18	53	880	97	44	35					
Average both species	46	65	5.0	490	26	53	498	62	49	43					
MINERAL SOIL (0 TO 10 INCHES)															
Red pine															
Menahga			5.5	1,002	[1/] 106(574)	112	881	83	2,870		1.29	5	8	87	6
Zimmerman			5.4	1,221	131(675)	126	908	93	2,920		1.31	4	9	87	6
Hiwood			5.1	1,462	29(542)	123	647	86	2,850		1.28	5	26	69	12
Aspen															
Hiwood			5.3	1,446	120(550)	147	878	117	2,780		1.25	6	20	74	14
Chisholm			5.3	918	70(229)	107	702	73	3,050		1.37	8	23	69	16
Faunce			5.7	1,600	39(179)	152	1,600	224	3,030		1.36	6	7	87	6
Average both species			5.4	1,275	82(458)	128	936	113	2,920		1.31	6	15	79	10
MINERAL SOIL (10 TO 40 INCHES)															
Red pine															
Menahga			5.4	814	155(339)	271	1,938	271	9,690		1.45	4	1	95	2
Zimmerman			5.6	996	493(1,158)	285	1,983	237	9,490		1.42	4	2	94	3
Hiwood			5.0	1,263	381(743)	177	1,747	362	9,290		1.39	3	22	75	10
Aspen															
Hiwood			5.8	1,328	589(944)	299	1,552	224	9,350		1.40	4	13	83	11
Chisholm			5.5	2,161	892(157)	1,112	16,990	4,248	10,490		1.57	22	34	44	14
Faunce			7.3	1,746	81(283)	373	19,575	1,352	10,090		1.51	6	2	92	2
Average both species			5.8	1,385	432(604)	420	7,298	1,116	9,730		1.46	7	12	81	7

1/ First value is P extracted with 0.01N HCl. Value in brackets is P extracted with Bray's No. 1 solution.

Table 3.--*Coefficients of variation of forest floor and mineral soil properties under red pine and aspen*

Sample identification	pH	N	P	K	Ca	Mg	Oven-dry weight	Ash	Bulk density	Sand	Silt + Clay	ΔH_2O
FOREST FLOOR												
Red pine												
Menahga	5.6	20	31	21	41	32	30	30				
Zimmerman	4.4	24	22	20	20	19	24	19				
Hiwood	3.4	31	28	30	29	23	24	34				
Average	4.5	25	27	24	30	25	26	28				
Aspen												
Hiwood	2.7	8	8	8	13	8	14	8				
Chisholm	2.8	17	26	24	16	19	17	6				
Faunce	3.1	9	12	13	23	15	11	15				
Average	2.9	11	15	15	17	14	14	10				
Average both species	3.7	18	21	19	24	19	20	19				
MINERAL SOIL (0 TO 10 INCHES)												
Red pine												
Menahga	4.6	7	20	19	34	23			6.7	2.5	17	12
Zimmerman	3.0	13	15	17	24	16			1.3	2.4	15	23
Hiwood	4.8	18	41	24	30	34			4.9	5.3	12	16
Average	4.1	12	26	20	29	24			4.3	3.4	15	17
Aspen												
Hiwood	5.9	9	31	20	35	32			5.7	4.8	14	9
Chisholm	2.9	9	24	20	16	20			2.8	8.9	19	14
Faunce	5.6	20	39	15	28	15			4.2	2.5	17	26
Average	4.8	13	31	18	26	22			4.2	5.4	17	16
Average both species	4.5	13	28	19	28	24			4.3	4.4	16	17
MINERAL SOIL (10 TO 40 INCHES)												
Red pine												
Menahga	3.5	15	25	21	29	45			4.8	1.2	22	24
Zimmerman	1.3	19	25	18	17	11			5.2	1.5	23	35
Hiwood	5.8	23	37	30	26	31			2.5	3.0	9	8
Average	3.5	19	29	23	24	29			4.2	1.9	18	22
Aspen												
Hiwood	5.9	14	42	17	24	24			2.2	4.2	20	12
Chisholm	7.4	19	18	27	8	22			3.7	8.5	7	12
Faunce	1.1	30	41	27	34	28			0.8	2.0	24	37
Average	4.8	21	34	24	22	25			2.2	4.9	17	20
Average both species	4.2	20	31	23	23	27			3.2	3.4	18	21

Table 4.--*Mineral soil samples needed to estimate mean ± 10 percent at 95 percent confidence level*
(In numbers)

Species and soil series	pH	N	P (0.1N HCl)	P Bray's 1	K	Ca	Mg	Bulk density	Sand	Silt + clay	ΔH_2O
0 TO 10 INCHES											
Red pine											
Menahga	1	2	21	11	18	60	28	3	1	14	8
Zimmerman	1	8	12	11	16	30	13	1	1	11	28
Hiwood	1	16	87	68	28	45	60	2	1	7	12
Aspen											
Hiwood	1	6	38	83	25	18	27	1	5	25	12
Chisholm	2	6	74	69	26	80	66	2	2	13	5
Faunce	2	26	103	20	16	51	16	1	1	19	45
Mean both species	1	11	56	44	22	47	35	2	2	15	18
10 TO 40 INCHES											
Red pine											
Menahga	1	12	32	44	22	42	105	2	1	25	30
Zimmerman	1	19	32	86	16	15	6	2	1	29	63
Hiwood	2	28	80	121	44	36	49	1	1	4	3
Aspen											
Hiwood	4	23	21	58	49	4	32	1	6	3	9
Chisholm	2	12	120	67	18	39	39	1	1	26	10
Faunce	1	62	111	84	48	77	50	1	1	37	89
Mean both species	2	26	66	77	33	36	47	1	2	21	34

Table 5.--*Soil samples collected from pits or tubes necessary to estimate mean of soil property ± 10 percent (at 95 percent level) in the 0 to 10 inch layer of mineral soil*
(In numbers)

Soil property	Pits		Tubes		Difference of means
	Mean1/	Range	Mean1/	Range	
pH	1	1 - 2	2	1 - 4	1
N	11	2 - 26	13	6 - 24	2
P (0.01N HCl)	56	12 - 103	116	31 - 281	60
K	22	16 - 28	39	22 - 75	17
Ca	47	30 - 80	62	9 - 147	15
Mg	35	16 - 66	57	4 - 168	22
Silt + clay	15	7 - 25	10	3 - 17	-5
Sand	2	1 - 5	1	1 - 2	-1
ΔH_2O	18	5 - 45	22	5 - 62	4

1/ The mean of three red pine and three aspen stands.

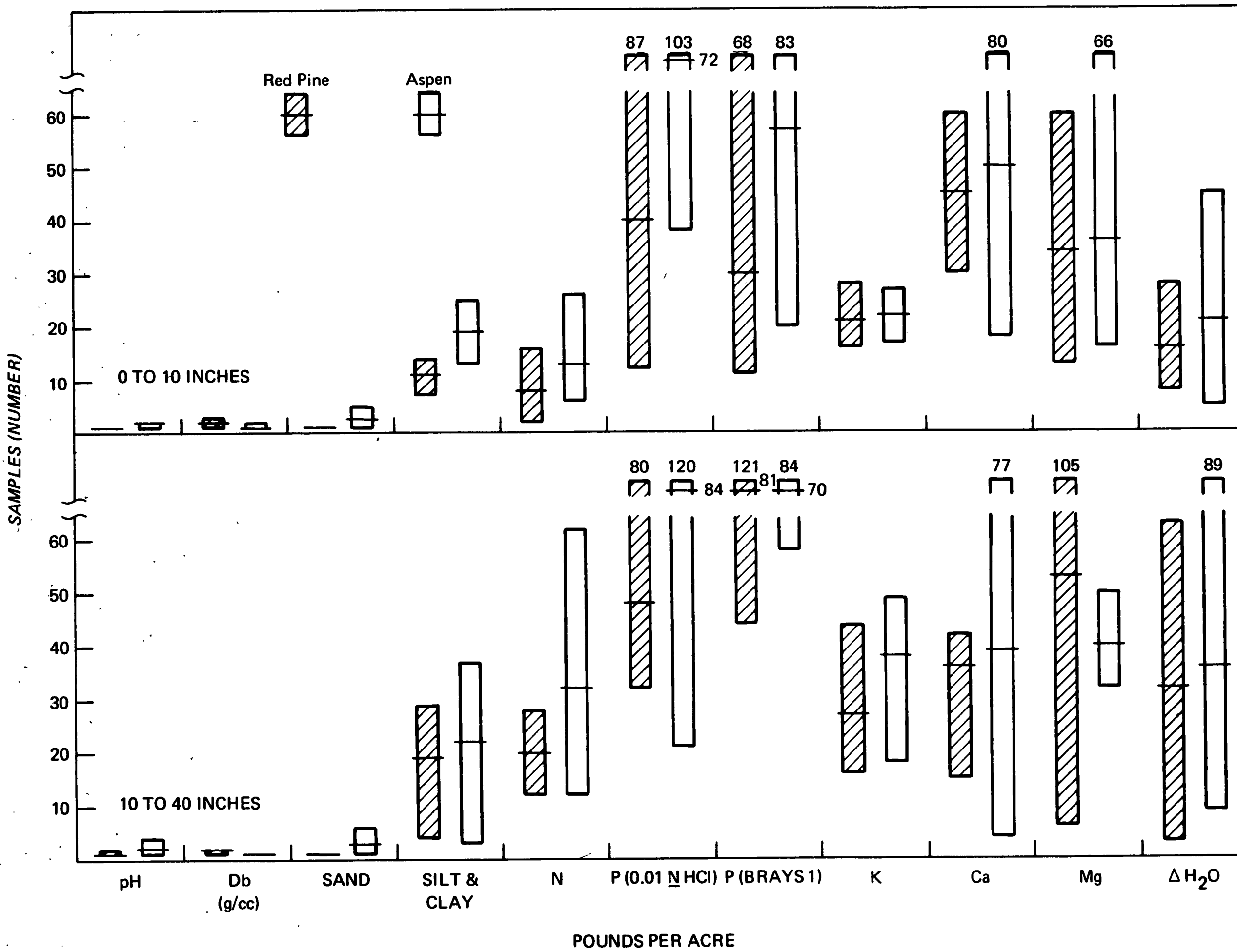

Figure 1.--*Number of mineral soil samples needed to estimate mean ± 10 percent at 95 percent confidence level. The extent of each bar represents the minimum and maximum of three sites, and the horizontal line through each bar indicates the mean of all three sites.*

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Sing along with Woodsy and help stop pollution.