SPATIAL VARIABILITY OF SOIL PROPERTIES IN RECLAIMED STRIP-MINED LANDS[1]

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ABSTRACT - Two fields on reclaimed mine sites in western North Dakota were chosen to determine the degree of variation on five soil properties and to estimate the sample size necessary to identify the statistical distribution with a prescribed level of confidence. With very few exceptions, all the set of measured values were characterized by normal distribution. The methods used to establish normality resulted in a useful measure of the goodness-of-fit of the normal distribution for the set of measured values. Variability differed among soil properties and changed with depth. The variability of the soil properties was greater at the Consolidation Site than at the North American Site. At the Consolidation Site the sample sizes required to identify the means with an 80 percent confidence level with ± 10 percent precision for 0.01 ha were found to be 1, 3, 2, 7 and 18 for the 0.3 and 15 bar, available soil water, sodium adsorption ratio and electrical conductivity, respectively. For the same soil properties at the North American 0.01 ha area sampling requirements were 1, 1, 2, 2, and 1 soil samples, respectively. Identical methodology could be used to study spatial variability of properties in natural agricultural soils.

Index terms: soil sampling, reclaimed mined soils.

VARIABILIDADE ESPACIAL DE ALGUMAS PROPRIEDADES EM SOLOS MINERAIS RECUPERADOS

RESUMO - Com o objetivo de determinar a variabilidade espacial de solos minerais recuperados, com respeito a cinco propriedades e estimar o número de amostras necessárias para identificar a distribuição estatística com um predeterminado nível de confiança, escolheram-se duas áreas representativas (Consolidation e North American) no Oeste do Estado de Dakota do Norte, E.U.A. Observou-se que quase sem exceção, todos os valores determinados foram caracterizados por uma distribuição normal. As metodologias usadas para estabelecer normalidade são uma forma muito prática para medir o ajuste da distribuição normal para qualquer propriedade. As variabilidades encontradas para cada uma das propriedades estudadas foram diferentes e variaram com a profundidade. A mesma foi maior na área de Consolidation do que da North American. Para a área de Consolidation o número de amostras necessárias para identificar as médias do conteúdo de água do solo a 0,3 bar, 15 bar, da água disponível, da relação de adsorção de sódio e da condutividade elétrica com um nível de confiabilidade de 80%, com uma precisão de ± 10% para 0,01 ha, foram 1, 3, 2, 7 e 18, respectivamente. Na área da North American, para identificar as médias destas mesmas propriedades, com idêntica confiabilidade e precisão, o número de amostras necessárias foram 1, 1, 2, 2 e 1, respectivamente. Idêntica metodologia poderá ser usada no estudo da variabilidade espacial de propriedades em solos agrícolas.

Termos para indexação: amostragem de solos, solos minerais recuperados.

INTRODUCTION

In determining soil properties there are three major sources of variation: laboratory, time and field (Cameron et al. 1971). Cline 1944 and Reed & Rigney (1947) and Hammond et al. (1958) indicated that laboratory variation is usually very small compared to field variation. Time variation, especially in the short term, is often masked by random field variability (Frankland et al. 1963, Mader 1963, and Ball & Williams 1968). Long term variation is easily measured. Thus, the largest and most significant variation in soil testing is spatial or field variation.

The spatial pattern of soil heterogenity influences the effectiveness of predictions based on samples composite from a given area, no matter how intensively the area is sampled (Cameron et al. 1971). Becket & Webster (1971) indicated that in nondisturbed soils up to half of the variability within a field may be present within any square meter. Raupach (1951) and Towner (1968) have shown that different treatments affect the soil to different depths and nutrient or water uptake are

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not always from the same depth. Also, depths of nutrient and water uptake will vary with the soil types. Thus, soil variability is not the same at all depths, nor does it change with depth in the same way for all soil properties.

The degree of variability in soils and the accuracy of mean plot values for soil properties is an important factor in sampling programs designed to describe and evaluate soils for agriculture use.

The main objective of the study is to present a simple methodology that permit to evaluate the spatial variability of soil properties and allows to determine the number of samples required to estimate the mean values of these to within a given percentage of accuracy.

MATERIALS AND METHODS

Two fields on reclaimed mine sites in western North Dakota were chosen for intensive grid sampling to determine the degree of variation in five soil properties. One field was at the Consolidation Company's Glenharold Mine (Consolidation Site). The other 30 miles to the west at the North American Coal Corporation's Indian Head Mine (North American Site). The fields were chosen to represent typical reclaimed areas at each mine. Typical data on characteristics of spoils at the mine sites are given in Table 1. A description of the fields and their grid sampling pattern is given in Table 2. A mixture of wheat grasses (Agropyron) have been growing on both fields since reclamation. Table 3 shows the particle size distribution of the soils.

Both areas were sampled to a depth of 120 cm at 30 cm intervals. Soil sample cores 3.71 cm diameter and 30 cm height were obtained using a tractor-mounted Giddings Hydraulic sampler. Samples were placed in plastic bags and transported to the laboratory for physical and chemical analysis.

TABLE 1. Properties of surface mine spoils at mine sites (Source: Sandoval et al. 1973).

Property	Consolidation	North American
Clay	52%	54%
pH	8,3	8,8
$CaCO_3$ equivalent	12%	10%
Electrical conductivity	2 mmhos/cm	2 mmhos/cm
Ca	1 meq/l	<1 meq/l
Mg	1 meq/l	<1 meq/l
Na	20 meq/l	19 meq/l
SO_4	16 meq/l	7 meq/l
Geologic group	Fort Union	Fort Union

Samples were air dried, crushed, and passed through a 2 mm sieve. Water holding capacities at 0.3 bar and at 15 bar were determined for the sites and depths sampled. A porous plate apparatus was used to determine moisture percentages at 0.3 bar of tension (Richards 1949). The water retained at 15 bar of tension was determined using a pressure membrane apparatus (Richards 1956). Available water was calculated as the difference between water content at 0.3 bar and that at 15 bar of soil water suction.

In order to characterize salinity and sodium status of the soils, saturation extracts of the soils were analysed in the laboratory for the electrical conductivity and concentration of calcium, magnesium, and sodium by atomic absorption techniques (Sandoval & Power 1978). These concentrations were used to calculate the sodium adsorption ratio of the saturation extract (Estados Unidos, 1954).

For each sampling depth the mean, standard deviation, coefficient of variation and index of skewness of the properties studied were obtained (Steel & Torrie 1960). The first three parameters were calculated to estimate soil variability. The index of skewness was obtained to identify the normal deviation from normality of the measured values.

The number of samples (N) required for 80 and 90 percent confidence limit ranges about the mean ± 10 and ± 20 percent were calculated for each site. The following equation was used to calculate the number of samples necessary to estimate the mean value of a property in a 0.01 ha tract for predetermined confidence intervals (Snedecor 1974):

$$N = \frac{t^2\ cv^2}{p^2}, \qquad (1)$$

where N is the number of samples per mine site, t is Student's t value for a given significance level (Steel & Torrie 1960), cv is the coefficient of variation found within the 0.01 ha tract for a single soil property data, and p is the percent allowable deviation from the mean.

RESULTS AND DISCUSSION

In Table 4 the values of the mean, standard deviation, coefficient of variation and index of skewness for five soil properties i.e. moisture retained at 0.3 & 15 bar of soil water suction, available water, sodium adsorption ratio and electrical conductivity for each soil depth of the sites studied are presented.

With the exception of the 0.3 bar water content data for the surface 30 cm at the Consolidation Site, all the soil characteristic data followed the normal frequency distribution, as described by the equation:

TABLE 2. Description of the fields and sampling grids.

	Consolidation site	North American site
Year of reclamation	Fall 1971	Fall 1973
Topography	Level to gently rolling	Level to gently rolling
Date sampled	August 1978	August 1978
Grid dimension (m)	9.15 x 9.15	9.15 x 9.15
Number of cores taken	56	56

TABLE 3. Particle size distribution of the soils*.

Soil depth (cm)	Per cent			Texture
	Sand	Silt	Clay	
Consolidation site				
0 - 30	14.0	43.0	43.0	silty clay
30 - 60	8.6	46.4	45.0	silty clay
60 - 90	14.3	43.4	42.3	silty clay
90 - 120	12.2	36.3	51.5	clay
North American site				
0 - 30	9.6	38.8	51.6	clay
30 - 60	12.0	39.0	49.0	clay
60 - 90	13.6	33.1	53.3	clay
90 - 120	11.8	36.0	52.2	clay

* Hydrometer method (Estados Unidos 1954)

$$f(x) = \frac{1}{\sqrt{2\ \Pi}} \exp\left\{- (x - m)^2 \ / \ 2\,\sigma^2)\right\}, \qquad (2)$$

where f is the frequency, m the mean, σ the standard deviation of the mean and x random variable.

The test for normality is illustrated in Figure 1 (A and B) for the soil water content retained at 0.3 bar of soil water suction. These figures are fractile diagrams showing the data for all the four depths of the Consolidation and North American Sites. The fact that untransformed values of water content follow a straight line relationship with a function of the type:

$$f(x) = \frac{x - m}{\sigma} \qquad (3)$$

indicates that the water content values are normally distributed. Similar plots indicating normal distributions at both sites were obtained for the 15-bar soil water content, available water, sodium adsorption ratio and eletrical conductivity data at each of the four soil depths. Student's test of symmetry used to judge the normality of sets of data confirmed the results obtained (Snedecor 1974).

At the Consolidation Site the water retained at soil moisture tensions of 0.3 and 15 bar as well as the available water generally increased with depth (Table 4), which is in accordance with textural classes. As indicated by the coefficients of variation, with a few exceptions variability increased with depth for all the properties studied. Further, the population of the soil water content at 0.3 bar have been found to decrease in skewness as the sampling depth increased, this means that as depth increased more values closer to the mean water content were obtained. As the sampling gets closer to the soil surface, more extreme values of soil water content were observed at the upper range of the population. This fact is also apparent in Fig. 1. Skewness of other soil water properties, though varied with depth did not show any definite trend.

At the North American Site the water contents at tensions of 0.3 bar and 15 bar and available water retention capacity varied very little with depth and did not show any definitive trend up or down with depth which may be due to the fact that not much of difference was observed in the clay content of various depths. Variability, as defined by coefficient of variation, changed irregularily with depth. Although not statistically significant, it was observed that for the available water retention capacity all the index of skewness were negative, indicating that most of the obtained values were smaller than the mean. With regard to

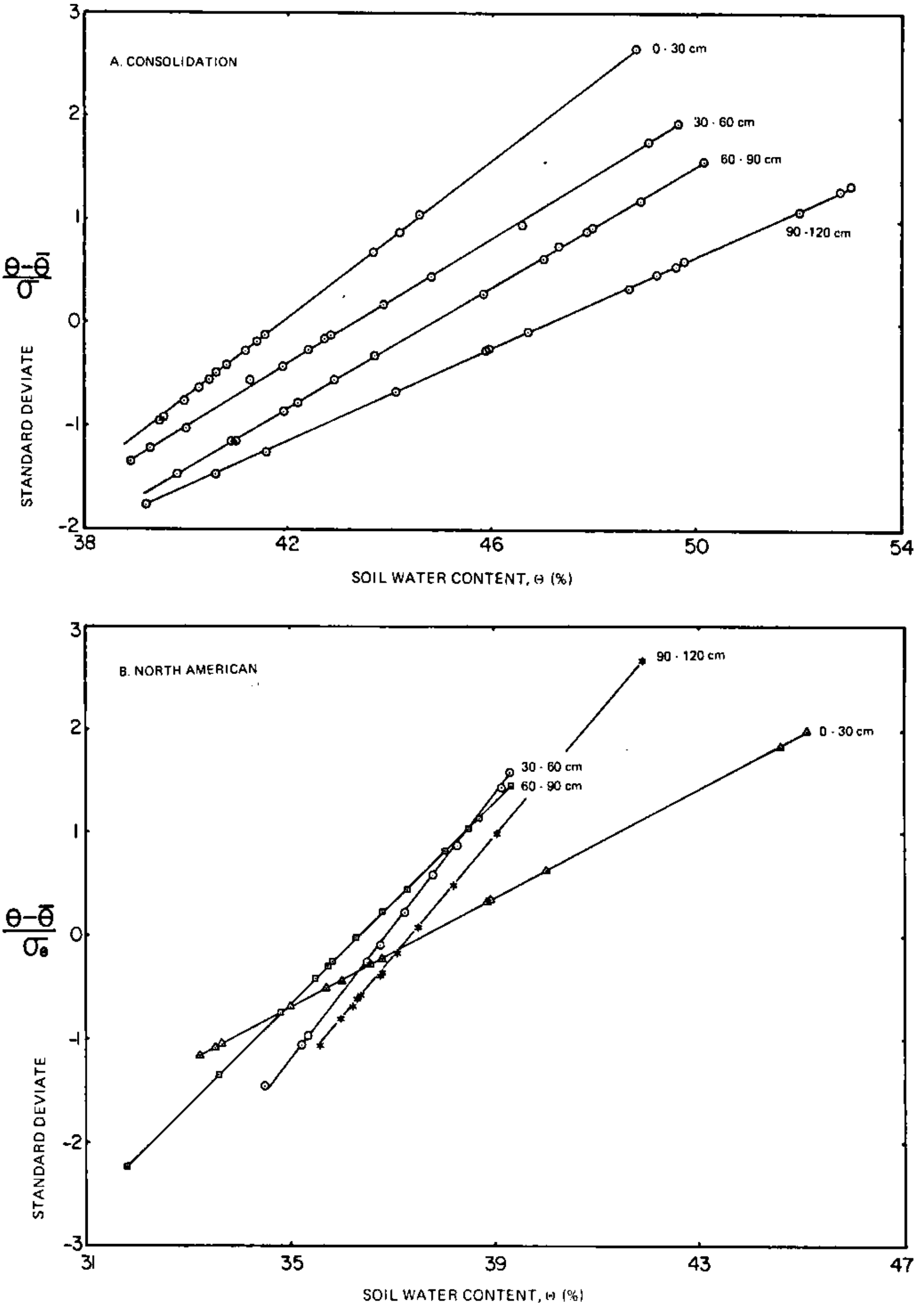

FIG. 1. Fractile diagram comparing water content at 0.3 bar soil water suction at different depths.
A. Consolidation Site,
B. North American Site. (Θ is the mean soil water content and σ the standard deviation of the mean).

chemical properties, sodium adsorption ratios decreased with depth but the coefficient of variation was the greatest at the deepest sampling depth, where as electrical conductivities did not show a definitive trend. As indicated by Becket & Webster (1971), chemical properties are more affected by management than physical properties. In the present study, higher coefficients of variation were calculated for electrical conductivity and sodium adsorption ratio than for the other properties at the Consolidation Site. At the North American Site, although the highest coefficient of variation was for the sodium adsorption ratio, in general the coefficients of variation of available soil water were high as well.

With the exception of the available water (0-30 cm), the variability of the soil properties was greater at the Consolidation Site than at the North American Site. Mean variabilities of soil properties at the Consolidation Site ranged from 6.15 to 39.05 percent while at the North American Site it ranged from 3.00 to 16.03 percent.

Available water and sodium adsorption ratio have been shown to be significantly correlated at mine sites in western North Dakota (Gee et al 1978, Carvallo et al. 1979). But in the present study no significant correlations were found between the available water and the sodium adsorption ratio of the soil. A possible reason for this is that the sodium adsorption ratios of sampling sites were not significantly different. Available water retention capacity was correlated (at 0.05 level) only with the sodium adsorption ratio data of the North American 30-60 cm depth interval.

Table 5 shows the number of samples for 0.10 and 0.20 confidence limits required to obtain estimated values within ± 10 and ± 20 percent of the mean for each of the five soil properties studied at each depth. The number of samples required increases with the level of accuracy and precision. Very high levels of accuracy and precision require unrealistically high numbers of samples. Properties with the higher variabilities also require more samples for a given limit of confidence. The choice of a realistic level of precision and degree of accuracy for sampling depends on a number of factors, usually the most important being resources of money and personnel. A 20-percent confidence level with a precision of 10 percent is probably adequate for predicting soil properties important in land reclamation work.

For the entire soil profile of the 0.01 ha of the Consolidation mined area, the average number of samples required to estimate the mean values of 0.3 bar, 15 bar, available water, sodium adsorption ratio, and electrical conductivity with a 20-percent confidence level within ± 10-percent precision, are 1, 3, 2, 7 and 18 respectively. For the same soil properties at the North American Site (0.01 ha), the sampling requirements are 1, 2, 2, 2, and 1 soil samples, respectively.

TABLE 4. Means, standard deviations, coefficients of variation and skewness for five soil properties sampled at four depths of sites studied.

Soil property	Statistical parameter	Soil depth (cm)			
		0 - 30	30 - 60	60 - 90	90 - 120
A. Consolidation site					
Soil water	Mean (%)	41.90	43.29	44.83	47.08
content at 0.3 bar	Standard deviation (%)	2.58	3.26	3.40	4.44
	Variation coefficient (%)	6.15	7.53	7.58	9.43
	Skewness	1.66**	1.13	0.79	0.02
Soil water	Mean (%)	20.09	21.63	22.37	22.17
content at 15 bar	Standard deviation (%)	2.10	3.07	2.93	2.91
	Variation coefficient (%)	10.48	14.21	13.10	13.13
	Skewness	0.65	0.12	0.40	0.79
Available	Mean (%)	21.81	21.66	22.46	24.91

TABLE 4. Continuation.

Soil property	Statistical parameter	Soil depth (cm)			
		0 - 30	30 - 60	60 - 90	90 - 120
Soil water	Standard deviation (%)	1.85	2.58	2.90	3.28
	Variation coefficient (%)	8.49	11.93	12.89	13.16
	Skewness	-0.44	0.56	1.15	0.63
Sodium adsorption ratio	Mean	16.64	17.85	18.00	16.82
	Standard deviation	1.74	4.03	2.75	4.48
	Variation coefficient (%)	10.46	22.57	15.27	26.63
	Skewness	0.24	0.70	0.39	0.35
Electrical conductivity	Mean (mmhos/cm)	5.09	5.31	5.30	4.89
	Standard deviation (mmhos/cm)	0.98	1.55	1.86	1.91
	Variation coefficient (%)	19.25	29.19	35.09	39.05
	Skewness	0.39	-0.56	-0.34	0.80
B. North American site					
Soil water content at 1/3 bar	Mean (%)	36.46	36.90	36.34	36.93
	Standard deviation (%)	2.16	1.58	2.06	1.11
	Variation coefficient (%)	5.92	4.28	5.67	3.00
	Skewness	0.006	0.05	-0.65	0.007
Soil water content at 15 bar	Mean (%)	17.82	18.55	18.30	18.54
	Standard deviation (%)	1.53	1.68	0.66	1.42
	Variation coefficient (%)	8.58	9.05	3.60	7.66
	Skewness	0.28	0.41	-0.22	-0.63
Available soil water	Mean (%)	18.64	18.49	18.03	18.39
	Standard deviation (%)	2.55	2.09	2.08	1.79
	Variation coefficient (%)	13.68	11.30	11.54	9.70
	Skewness	-0.32	-0.35	-0.54	-0.58
Sodium Adsorption ratio	Mean	13.43	13.07	12.14	11.79
	Standard deviation	1.09	0.83	1.10	1.89
	Variation coefficient (%)	8.11	6.35	9.06	16.03
	Skewness	0.64	0.82	0.09	0.49
Electrical conductivity	Mean (mmhos/cm)	6.00	6.30	6.00	5.80
	Standard deviation (mmhos/cm)	0.50	0.37	0.39	0.48
	Variation coefficient (%)	8.33	5.87	6.48	8.27
	Skewness	0.11	0.64	1.23*	0.82

* Significant at 0.05 level by the Student's t test.

** Significant at 0.01 level by the Student's t test.

TABLE 5. Number of samples required at the studied sites to estimate the mean within a specified level of accuracy and precision.

Soil property	0.10 Level				0.20 Level				0.10 Level				0.20 Level			
	Within 10 percent of mean								Within 20 percent of mean							
	Number of samples*								Number of samples*							
A. Consolidation site																
0.3 bar percentage	1	2	2	3	1	1	1	2	1	1	1	1	1	1	1	1
15 bar percentage	3	6	5	5	2	4	3	3	1	2	1	1	1	1	1	1

TABLE 5. Continuation

Soil property	0.10 Level Within 10 percent of mean Number of samples*				0.20 Level Within 10 percent of mean Number of samples*				0.10 Level Within 20 percent of mean Number of samples*				0.20 Level Within 20 percent of mean Number of samples*			
Available soil water	2	4	5	5	1	3	3	3	1	1	1	1	1	1	1	1
Sodium adsorption ratio	3	16	7	22	2	9	4	13	1	4	2	5	1	2	1	3
Electrical conductivity	11	26	38	47	7	15	22	27	3	7	10	12	2	4	6	7
B. North American site																
0.3 bar percentage	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15 bar percentage	2	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1
Available soil water	6	4	4	3	3	2	2	2	1	1	1	1	1	1	1	1
Sodium adsorption ratio	2	1	2	8	1	1	1	5	1	1	1	2	1	1	1	1
Electrical conductivity	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1

* The four consecutive number of samples shown for each confidence interval and degree of precision correspond to the depth intervals 0 - 30, 30 - 60, 60 - 90, and 90 - 120 cm, respectively.

CONCLUSIONS

1. The methods used to establish normality resulted in a useful measure of the goodness-of-fit of the normal distribution.

2. With few exceptions, all the set of measured values were characterized by normal distributions.

3. Variability differed among soil properties and changed with depth.

4. The variability of the soil properties was greater at the Consolidation Site than at the North American Site and hence more samples are required to identify, at a given confidence level, the property means at the former site than at the North American.

5. Identical methodology could be used to study spatial variability of properties in natural agricultural soils.

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