A reprint from

communications in
soil science
and
plant analysis

Communications in Soil Science and Plant Analysis

Communications in Soil Science and Plant Analysis presents current and important papers, symposia, and reviews in all areas of crop production, devoting particular attention to the mineral content of soils and plants and plant nutrition. This unique publication fully examines soil chemistry, minerology, fertility, soil testing, soil-crop nutrition, plant analysis, mineral metabolism and plant physiology, methods of soil and plant analysis, liming and fertilization of soils, and techniques for correcting deficiencies. International in scope and application, the journal considers plants and soils of all climates, including subtropical and tropical. In addition, its direct reproduction format permits rapid publication of important developments, keeping readers abreast on research at the frontiers of their field.

Whether engaged in basic or applied investigations or in communicating techniques and information directly to growers, **Communications in Soil Science and Plant Analysis** provides an excellent source and forum for agronomists, horticulturalists, floriculturalists, and foresters concerned with increasing crop yields.

COMMUN. IN SOIL SCI. PLANT ANAL., 22(3&4), 205-212 (1991)

SPATIAL VARIABILITY OF SELECTED CARBON, NITROGEN, AND PHOSPHORUS PARAMETERS ON ACID AND CALCAREOUS RANGELAND SOILS

R. A. Bowman

USDA-Agricultural Research Service, Crops Research Laboratory, 1701 Center Ave., Fort Collins, CO 80526

ABSTRACT: The magnitude of C, N, and P seasonal or long-term variability in rangelands is difficult to assess because of intrinsic soil heterogeneity even in seemingly uniform areas. A need exists, therefore, to determine the minimum number of samples necessary so significant changes in C, N and P can be assessed where minimal confounding from soil types and vegetation exist. To achieve this end, laboratory and field studies of selected C, N, and P parameters were conducted to compare variability among six transect lines, radiating from a central point. Samples were taken along each transect line every 3 m to a distance of 15 m. Parameters measured were: total organic C (OC), total Kjeldahl N (TKN), NH_4-N, NO_3-N, $NaHCO_3$-extractable inorganic P (NaHP), and total organic P (TPo). Two rangeland soils, a moderately acid Ascalon sandy loam, and a calcareous Haverson loam, were sampled at two depths to assess spatial differences. Results indicated that under the experimental conditions, OC, TKN and TPo would require at least 9, 6, and 10 replications, respectively, for 95% confidence limit for an allowable error of 10%. The smaller available mineral pools were much more variable than the total pools, and could require as many as 20 to 30 samples.

INTRODUCTION

Quantification of C, N, and P changes in field studies is complicated not only by the reproducibility of specific assays from supposedly uniform samples, but also to a greater extent by soil heterogeneity (1). Since spatial variability of soil C, N, and P cannot be completely eliminated, reseachers need to know the variances associated with different sampling plans for specific analyses. Once spatial variability has been assessed, then differences in seasonal or long-term C, N and P dynamics (temporal variability) can be more readily quantified (2).

Various studies have addressed nutrient variability in forest and cultivated soils. NcNabb et al. (3) studied variability of C and N in surface forest soils in the Oregon Cascades. Their results showed that 28 samples were needed for C, and 23 samples for N for accurate field representation. Harrison (4) compared variation of four P indices in woodland soils in the United Kingdom. He measured available P, organic P, total P, and phosphatase activity. Although there were significant spatial differences in certain P indices, he found that bulk density and horizon depth in the soil profile were more important sources of variation than P properties. Similarly, Sharpley and Smith (5) did not attempt to separate P spatial variability in virgin and cultivated soils because in most instances, management (cultivation and grazing) created significantly larger differences in P measurements than did field spatial differences.

For studying rangeland soils, a need exists to investigate the magnitude of field spatial variability so that short-term or long-term C, N, and P changes can be assessed even in seemingly uniform areas. On a seasonal basis, the concentration of available N and P in the soil solution, and the rate of release of N and P from the soil organic matter and from solid phase mineral might change. The selectivity of range species to utilize N and P differentially over the season could result in further changes (6). Additionally, over the long term, water and wind erosion could also cause substantial changes in and redistribution of C, N, and P.

The purpose of this study, therefore, was to evaluate in relatively uniform rangeland soils, the spatial variability of selected routinely measured C, N, and P parameters so signiiicant differences from specific treatments or natural changes over time (temporal variability) can be assessed. These rangeland soils are usually more homogeneous than cultivated soils because they generally lack confounding due to fertilizer applications and placements, and to textural variations due to mixing by plowing and subsequent removal of clay and silt by erosion. The size of the sampling area can, therefore, be regarded as a minimum for soils in the area (both rangeland and cultivated) having similar characteristics (7).

MATERIALS AND METHODS

__Site Description:__ The research was conducted at the Central Plains Experimental Range in north central Colorado. The area is part of the Shortgrass Steppe, and its major soils, climate, and dominant vegetation have been described elsewhere (8,9,10). To minimize complications due to slope, aspect, and major vegetation changes, relatively flat areas (0-3% slope) were chosen with blue grama [*Bouteloua gracilis* (H. B. K.) Lag.] as the dominant vegetation. Two different sites were selected, an Ascalon sandy loam (a dominant soil type in the central Great Plains) and a Haverson loam. The Ascalon soil is a moderately acid soil found on upland sites with cacti (*Opuntia polyacantha* Haw.) as a secondary species; the Haverson soil is a calcareous soil found on flood plains and adjacent stream terraces with fourwing saltbush [*Atriplex canescens* (Pursh) Nutt] as a secondary species. Both areas receive about 310 mm of precipitation annually, the bulk of which occurs between May and September. Total annual productivity is about 800 kg of dry matter per ha for the upland site, and about 1200 kg/ha for the flood-plain site.

For determining the field spatial variability of C, N and P parameters, six equidistant transect lines were selected radiating from a central point. Soil core samples were taken on June 6, 1987, every 3 m to a distance of 15 m from the central point in 0- to 10- and 10- to 20-cm depth increments. Each sample represented a composite of three subsamples 2 cm in diameter. Soil samples from an independent transect line were analyzed for pH (10.0 g soil:25 mL water), texture (hydrometer), and bulk density (single cylinder of 284 cc volume).

Carbon, N and P Measurements: Organic carbon (OC) was determined by the Walkley-Black procedure (11) after all visible litter was removed. A colorimetric procedure was used for the estimation of OC (12). Total Kjeldahl N (TKN) was determined by a sulfuric acid-peroxide digestion (13), and NH_4-N and NO_3-N by KCl extraction (14). Nitrogen in the digests and extracts was determined colorimetrically at the Colorado State University Soil Testing Laboratory. Sodium bicarbonate-extractable inorganic P (NaHP) was determined by the Olsen procedure (15), and total soil organic P (TPo) by a dry combustion method (16). An analysis of laboratory variability was also conducted on all six parameters.

Statistics: Since systematic sampling was used instead of random sampling, a test for homogeneity of transect variances was determined from a scatter diagram of means and variances (1). Parameters that showed non-significant variances were then pooled. For all C, N and P parameters at both depths, the average (X), coefficient of variation (CV%), and number of samples (n) required for 95% confidence level for an allowable error (E) of $\pm$ 10% of the mean (17) were determined on the pooled samples according to the following equation:

$$n = (t)^2 \ (CV\%)^2 \ / \ (E\%)^2.$$

The t refers to Student's t-value at $p = 0.05$ for a given number of observations.

RESULTS AND DISCUSSION

Laboratory Variability: Before an analysis of field spatial variability was determined, an assessment of laboratory variability of throughly mixed 2-mm soil samples was conducted (Table 1). Results from the data indicated that routine replicate analyses from the same soil sample for OC and TPo should improve data accuracy while data for TKN and NaHP showed that, generally, these parameters do not need same sample replication. Variability in mineral N was more a function of the levels of extractable N, greater reproducibility and lower CVs being obtained with larger mineral N pools. Values for NO_3-N exhibited the highest CVs of all six parameters.

Field Variability: Areas uniform in topography and vegetation were selected to minimize confounding of slope and major changes in dominant vegetation. The bulk density and textural data (Table 2) confirmed the relative uniformity of the two soils in the 0-10 cm depth. Texture was much more variable in the 10-20 cm depth. Generally, CVs were less than 5% for the top soil for all parameters, but greater than 10% for the lower depth for texture. Because of a combination of factors such as erosion, temperature, vegetation and litter, one would expect the 0- to 10-cm depth to be more variable than the 10- to 20-cm depth. While this was generally the case for the six parameters, eluviation of clay, especially in the Ascalon soil, was variable enough to cause greater differences in the 10- to 20-cm depth.

From an analysis of the scatter diagrams for field samples (data not shown), variances for OC, TKN, and TPo were not significantly different for the six transect lines, and were, therefore, combined. Reed and Rigney (2) used a similar approach in their systematic grid sampling for soil spatial variability. Thus, CV and n were calculated for all 30 sampling sites. This was not the case for the labile mineral pools. Generally, variance from one transect line was significantly different from the others, and was, therefore, elimimated from the pooled variances.

Of all six parameters, TKN was the least variable, and mineral N (especially

Table 1. Laboratory variability of six selected soil parameters. n = 6.

Soil Parameter	Ascalon 0-10 cm	Ascalon 10-20 cm	Haverson 0-10 cm	Haverson 10-20 cm
	CV(%)			
OC	8.7	8.2	8.6	7.9
TKN	2.5	3.7	1.6	2.2
NH_4N	8.7	8.2	7.8	8.5
NO_3-N	14.8	12.6	13.7	12.3
TPo	9.5	6.7	11.0	6.0
NaHP	1.9	3.1	2.2	1.0

Table 2. Average (X) and CV of selected physical and chemical characteristics of one transect line of Ascalon and Haverson soils.

Soil Parameter	Ascalon (Depth,cm) 0-10	Ascalon (Depth,cm) 10-20	Haverson (Depth, cm) 0-10	Haverson (Depth, cm) 10-20
pH (X)	6.4	6.5	8.1	8.1
(CV%)	4.09	4.63	1.40	1.61
Bulk Density (g/cc) (X)	1.37	1.36	1.18	1.13
(CV%)	4.99	3.15	5.78	2.94
Sand (%) (X)	62.0	54.0	31.0	22.0
(CV%)	2.0	13.5	14.0	10.8
Silt (%) (X)	19.0	16.0	37.0	43.0
(CV%)	8.1	20.0	10.0	2.0
Clay (%) (X)	19.0	30.0	32.0	35.0
(CV%)	4.0	13.0	10.0	8.4

* Ascalon is a Fine-loamy, mixed, mesic Aridic Argiustoll. Haverson is a Fine-loamy, mixed (calcareous), mesic Ustic Torrifluvent.

NO_3-N) the most variable (Table 3). Generally, the data from total pools (TKN, TPo, OC) showed lower CVs than those from the lower mineral pools. For both soil depths, results indicated that OC and TPo values could vary by about 60 to 80%, and TKN by about 25-50%. Because of the small pool sizes for the other parameters, sample values varied by > 100%.

Table 3. Selected statistical parameters for field variability of Ascalon and Haverson soils.

Soil Parameter	Min	X	Max	CV	n	Min	X	Max	CV	n
	Statistical Parameter									
	mg/kg			%		mg/kg			%	
	Ascalon					Haverson				
	0 - 10 cm									
OC	6800	9071	12680	19.5	16	12800	16100	20900	15.0	9
TKN	850	1090	1190	12.0	6	1250	1417	1680	13.0	7
NH_4N	0.8	1.8	3.4	20.4	17	0.8	1.7	2.9	19.1	15
NO_3N	1.7	2.6	6.0	25.4	26	3.8	5.2	7.1	18.7	15
TPo	72	114	159	19.0	15	106	157	199	17.0	12
NaHP	5.7	10.7	15.6	17.0	12	2.2	4.6	6.4	20.7	18
10 - 20 cm										
OC	5850	7700	10800	18.0	14	7000	9800	13900	16.2	11
TKN	740	940	1140	12.6	7	820	1010	1200	10.5	5
NH_4N	1.0	4.0	1.9	22.0	21	0.7	1.3	2.6	27.0	30
NO_3N	1.5	2.7	8.4	30.0	37	3.0	4.4	9.2	28.0	32
TPo	102	151	172	22.0	20	91	126	158	15.5	10
NaHP	2.8	4.6	6.1	22.4	21	1.8	2.4	3.0	13.0	7

Once CV values were established for the field sites, statistical equations were used to calculate the number of replications needed for a given level of confidence and a given percent allowable deviation from the mean. The CV values in Table 3 can now be used to calculate the number of samples or replications needed for a desired statistical confidence. The number of replications (n) ranged from 5 for TKN (Haverson, 10-20 cm), to 37 for NO_3-N (Ascalon, 0-10 cm).

If one assumes normal distribution in sample values, results in Table 3 can also be used to calculate minimun changes required for measuring significant temporal differences. In the case of OC, new means (seasonal, temporal) must be about ± 20 to 30% of the baseline mean value for 95% confidence intervals [(X±(2.06)(std. dev./5)]. For NO_3-N, values must be about ± 60%, and for TKN, about ± 20%.

Since parent material, climate, and relief were generally the same, some of the differences for the available pools (NO_3-N, NH_4-N, NaHP) could be attributed to localized disturbances or patch dynamics. Where die-out of blue grama had occurred in recent times (18), significant differences existed between die-out and healthy intact areas for these available pools.

From these data and those previously published (2,3,4), it would appear that studies for assessing temporal variability may require a lot more rigor in returning to as near to the baseline sampling site as possible. Generally, this was borne out by the greater similarity between means (data not shown) for adjacent (3 m) concentric circles. This requirement could be especially critical for parameters which pool sizes are dependent upon microbial and enzymatic processes (mineral N, NaHP, microbial C, N, and P pools, mineralizable N). However, for fertility purposes where ranges of values are more important than absolute amounts, sampling does not need to be as rigorously controlled.

REFERENCES:

1. Gomez, K. A., and A. A. Gomez. 1984. Statistical Procedures for Agricultural Research. John Wiley and Sons, New York, NY.

2. Reed, J. F., and J. A. Rigney. 1947. Soil sampling irom fields of uniiorm and nonuniform appearance and soil types. J. Am. Soc. Agron. 39:26-40.

3. McNabb, D. H., K. Cromavk, Jr., and R. L. Fredriksen. 1986. Variability of nitrogen and carbon in surface soils of six forest types in the Cascades. Soil Sci. Soc. Am. J. 50:1037-1041.

4. Harrison, A. F. 1977. Variation of four phosphorus properties in woodland soils. Soil Biol. Biochem. 11:393-403.

5. Sharpley, A. N., and S. J. Smith. 1983. Distribution ofphosphorus in virgin and cultivated soils and potential erosion losses. Soil Sci. Soc. Am. J. 47: 581-586.

6. Andrew C. S., and C. Johansen. 1978. Differences betweenpasture species in their requirements for nitrogen and phosphorus, pp. 111-127. IN: J. R. Wilson (ed.) Plant Relations in Pasture. CSIRO, E. Melbourne, Australia.

7. Ball, D. F., and W. M. Williams. 1968. Variability of soil chemical properties in two uncultivated brown earths. J. Soil Sci. 19:379-391.

8. Sims, P. L., J. S. Singh, and W. K. Lauenroth. 1978. The structure and function of ten Western North American Grasslands. 1. Abiotic and vegetational characteristics. J. Ecol. 66:251-285.

9. Parton, W. J., and D. Greenland. 1987. Climates of long-term ecological sites: Central Plains Experimental Range. Occasional Paper No. 44. Institute of Artic and Alpine Research. University of Colorado, Ft Collins, CO.

10. Lauenroth, W. K., and D. G. Melchunas. 1988. The Shortgrass Steppe. In R. T. Coupland (ed.) Ecosystems of the World. Vol. 8 Natural Croplands. Elsevier Scientific Co. New York, NY.

11. Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter, pp. 539-579. IN: A.L. Page et al. (eds.) Methods of Soil Analysis. Part 2, 2nd. ed., Agronomy Monograph No. 9. American Sociey of Agronomy, Madison, WI.

12 Heanes, D. L. 1984. Determination of total organic C in soils by an improved chromic acid digestion and spectrophotometric procedure. Commun. Soil Sci. Plant Anal. 15:1191-1213.

13. Bremner, J. M., and C. S. Mulvaney. 1982. Nitrogen-Total, pp. 595-624. IN: A. L. Page et al. (eds.). Methods of Soil Analysis. Part 2, 2nd ed. Agronomy Monograph No. 9. American Society of Agronomy, Madison, WI.

14. Keeney, D. R., and D. W. Nelson. 1982. Nitrogen- Inorganic forms, pp. 643-696. IN: A. L. Page et al. (eds.) Methods ot Soil Analysis. Part 2, 2nd. ed., Agronomy Monograph No. 9. American Society of Agronomy, Madison, WI.

15. Olsen, S. R., C. V. Cole, F. S. Watanabe, and L. A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U. S. Dept. of Agric. Circ. 939. U. S. Government Printing Office, Washington DC.

16. Saunders, W. M. H., and E. G. Williams. 1955. Observations on the determination of total organic phosphorus in soils. J. Soil Sci. 6:254-267.

17. Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods. 6th. ed. The Iowa State University Press, Ames, IA.

18. Bowman, R. A., and W. A. Laycock. 1981. Soil Investigations into the dieoff of blue grama at the Central Plains Experimental Range. SRM Abs., p. 5. Society for Range Manage., Denver, CO.