SPATIAL VARIABILITY OF SOIL TEST PHOSPHORUS, POTASSIUM, pH AND ORGANIC MATTER CONTENT

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Abstract

As part of a larger study investigating the potential for variable fertilizer N application in corn production, 18 field sites were established on farms across Ontario intensively sampled in the 1995 and 1996 field seasons to assess the spatial variability of soil test P, K, pH and organic matter content. Soil parameters typically display a log-normal distribution (positive skew) which would generally result in the under-fertilization of a greater area of a field if the rate of fertilization was based on the average soil test value for the field. The standard commercial grid size of 1 ha would not be adequate to characterize the spatial variability of all the measured soil parameters at any of the sites. Sampling according to either slope position or elevation would appear to give little improvement in characterizing the soil variability present at these sites.

Introduction

The concept of variable application of fertilizer materials is one that intuitively makes sense. It has long been recognized that soil fertility levels are spatially variable within a field, and that fertilizing according to the average soil test will result in the over and under-fertilization of various parts of a field. Ideally, the profitability of implementing a variable rate fertilization program will depend upon the value, variability and the spatial scale of soil fertility levels. These parameters effectively define the likelihood of a crop response to applied fertilizer, the amount of fertilizer to be applied at different locations within a field and the scale at which variable fertilizer application will need to be applied to effectively managed the spatial variability present in soil fertility. Ultimately, however, it is the spatial response of crop yields to variable fertilizer inputs that will determine the profitability of variable rate fertilization. This response is not only a function of how well the variability of soil fertility has been predicted, but it is also a reflection of other soil or site characteristics that may impact upon the response of the crop to applied fertilizer. In other words, soil fertility is not the only factor which affects the most economic rate of variable fertilizer application.

Considerable attention has been paid to the spatial characterization of soil properties in attempts to conduct site-specific crop management (Robert et al. 1993, 1995, 1996, 1999; Stafford 1997, 1999). McBratney and Pringle (1997) have outlined some of the more common geostatistical approaches for quantifying soil variability. Probably one of the most common procedures is the use of semivariance and variograms to measure the spatial dependence of soil properties, an important criteria for determining sampling intervals for the spatial prediction of soil properties. These authors also present a review of published variograms for soil properties typically associated with precision agricultural studies (i.e. soil pH, soil test P and K, organic matter content etc.) which clearly demonstrate site and parameter specific spatial scales of variability. This paper examines the spatial dependence of selected soil properties in 18 Ontario farm fields and the potential implications for using grid sampling or directed sampling based on topography for predicting soil fertility levels.

Materials and Methods

In the spring of 1995 and 1996, a total of 18 fields (10 to 25 ha in size) were soil sampled (0-15 cm) on a 30-m grid for soil test P (sodium bicarbonate extractable), soil test K (ammonium acetate extractable), pH (water paste) and organic carbon content (Lecco C analyzer). A high-resolution differential global positioning system mounted on an ATV was used to create a detailed elevation map of each field. All fields had a cropping rotation of either corn-soybean or corn-soybean-small grain, and tillage systems varied from conventional to no-till. Sampling was done in the year of corn production avoiding the current year fertilizer bands. All farm operation were conducted by the farm cooperators, following their normal production practices.

The spatial structure of measured soil parameters was characterized using GSTAT Version 2.1.0 (August 1999, Copyright (C) 1992, 1999 Edzer J. Pebesma). As commonly seen with soil properties, most parameters followed a log-normal distribution with a positive skew. Thus a log transformation of the data was performed prior to variogram analysis. In general the spatial structure could be explained with an exponential model, and only in a couple of instances was this model not the most appropriated. As a result it was decided to use only the exponential model for all the cases for ease of comparison of attributes and fields. Omnidirectional and directional variograms were generated, and the one with the smaller variance or better spatial structure selected. Finally a model was fitted to the selected sample variogram (GSTAT uses several least squares estimate fitting methods). Relationships between soil and site parameters were examined using correlation analysis (SAS 1999).

Results and Discussion

Soil Test P, K and pH

Most fields displayed considerable variability in terms of the field average and ranges of values for the measured parameters (Table 1). Since corn has the highest fertility requirements of the crops in the rotations of each of these sites, assessment of the fertility status of the fields was made based on the fertilizer requirement of this crop as outlined in OMAFRA Pub. 296. Based on the mean soil test for each field two of the 18 sites would have a zero fertilizer recommendation for P and 13 of the 18 sites would have a zero fertilizer recommendation for K. Based on the minimum soil test values, the results from site 16 would indicate no need for either P or K fertilizer at any location in this field. These elevated soil test levels undoubtedly reflect the long history of manure application prior to the start of this study.

Soil test P levels ranged from low (0-9 ppm) to either very high (between 31-60 ppm) or excessive (>60 ppm) (OMAFRA Pub. 296) in all but two fields (sites 5 and 16). Similarly in most fields soil test K levels also ranged from either low (0-60 ppm) or medium (61-120 ppm) to very high (151-250 ppm) or excessive (>251 ppm). The accompanying recommended fertilizer applications rates for these fields would vary between 0 and 100 kg P_2O_5 ha^{-1}, and 0 to 160 kg K_2O ha^{-1} suggesting that at least the criteria of having suitable ranges in soil test levels to possibly make variable rate applications worthwhile has been met.

Although not presented, the population statistics for soil test P and K in general indicated that soil test levels were not normally distributed, but rather log-normal. This positive skewness is a common feature of soil test properties and it illustrates the inherent problem of field variability and fertilization to an average soil test as pointed out by Kachanoski and Fairchild (1995). The positive skewness in the data results in the mean value for the field being greater than the median value. Thus, by applying fertilizer to the meet the average need of the field a greater area of the field is likely to be under-fertilized than over-fertilized. The degree to which this becomes a problem depends on the soil test level and the variability of the soil test values. Presented in Table 2 are the relative proportions of the individual fields that would be either under, over or properly fertilized if constant rate of fertilizer was applied based on the field average soil test. This calculation assumes that the measured soil test values accurately reflect the fertilizer requirement for the corn crop growing in that area of the field. In general, as average soil test levels decrease, the population tends to become more log-normal and as such the proportion of the field which is under-fertilized increases. For example, the soils which would be considered low or medium in average soil test P (P of <16 ppm) showed considerable areas which were under-fertilized. When the average soil test P level approached 30 ppm (level at which no fertilizer P is required), the area of the field predicted to be over-fertilized increases considerably.

Soil pH values were also found to be fairly variable (Table 1). The average pH value of the fields indicated that only 3 sites (sites 10, 14 and 18) would require lime application for soybean production (i.e. average pH values were below 5.6). However, the proportion of these three fields requiring lime ranged between 45 and 61%. Sites 3, 9, 11, 13 and 17, had average soil pH values that would indicate no need for lime, yet the proportion of these fields with pH values below 5.6 were, 28%, 32%, 41%, 11% and 10% respectively. As indicated in Table 1, there were some very low pH value observed (many below 5). On selected sites these low pH values were verified by repeated analysis on the original samples, and a re-sampling of transects through the problem areas.

Spatial Variability of Soil Test P, K and pH

Parameters for the exponential model of the variograms indicate considerable difference between fields in terms of the spatial dependence of soil properties (Table 3). The nugget variance (C_0) represents the inherent random variation in the soil property. A soil parameter with a relatively large C_0, compared to the total variance ($C_0 + C$) indicates that either that parameter has very little spatial dependence or that the sampling interval was too large to detect the range of spatial dependence. Out of the 18 sites, the nugget effect accounted for less than 30% of the total variance in 14, 12 and 13 of the sites for soil test P, K and pH, respectively. The pH data for site 2 had a nugget effect that accounted for all of the observed variance indicating that either there was no spatial dependence of pH, or that a 30 m grid was too large a sampling interval. Sites 3 and 13 were the only sites which showed relatively a large nugget in all three of the measured soil properties.

The range of spatial dependence varied between sites and with soil property measured (Table 3). As indicated before, no spatial dependence was observed for pH at site 2. Of particular importance is the fact that the range of spatial dependence was not similar within a given site for the three soil properties measured. From a practical point of view, if one is sampling a field to predict the variable application of several crop inputs (i.e. different fertilizers and lime), one needs to select the parameter with the shortest range of spatial dependence to established the most appropriate sampling interval for all measured parameters (assuming of course that this parameter offers some management opportunity). Of particular interest is how the range of spatial dependence observed in this study matches to the common 1 ha (2.5 ac) grid sampling that appears to be the standard commercial grid size adopted for mapping soil properties for site-specific applications. Given that a general rule of thumb is to set the sampling interval at one-third of the range of the variogram model in order to produce a reasonable interpolation of soil properties between sampling points, it is quite clear from Table 3 that a 1 ha sampling grid (i.e. 100 m interval) would be inadequate for all of these sites. In fact, using this criteria, soil K at site 12 and soil pH at site 14 are the only two soil parameters that would presumably be adequately mapped using a 1 ha grid. Frogbrook (1999) found a similar inadequacy in using a 1 ha grid sampling for soil test K in a study in Britain. For our sites, the appropriate sampling intervals were 10 to 50 m for P, 10 to 220 m for K and 0 to 90 m for pH. These sampling intensities are likely to remain economically unfeasible based on current sampling and analytical technologies.

Soil Variability in Relation to Elevation and Landscape Position

Sampling of soil properties according to landscape position has been suggested as one possible means to better characterize the variability within a field. Preliminary work in Ontario had revealed that while soil test levels were often correlated to elevation or slope position, the variability within a given slope class was often almost as great as that within the entire field (Kachanoski personal communication). Similar observations were made in this study. Typical results are presented in Table 4 which reports the mean values and ranges for the measured soil properties according to landscape position for site 3. Each slope class generally displays a similar mean and range of values suggesting little benefit in sampling by topography for improving the prediction of these soil properties at this site. Similar results were observed on the other sites, which implies much of the variability in soil test P and K in these fields appears to be associated with farming activities rather than other pedogenic processes.

Use of covariate analysis has also been suggested as a method of improving the spatial prediction of a soil property that is either difficult or expensive to measure by establishing its relationship to a parameter that is easier to characterize spatially (McBratney and Pringle 1997). For example, black and white aerial photographs may give adequate estimates of variations in soil organic matter contents which in turn may be related to a soil property of interest. But once again, these relationships may need to be established for individual sites. Simple correlation tables of the parameters did reveal that the parameters were correlated to one another at some sites, however, the strength and sign of the correlation varied from site to site (Table 5).

Summary

The variability that exists in soil properties is often site-specific and the sampling intensity required to characterize that variability is also likely to be both site and parameter specific. Sampling on a 1 ha basis is unlikely to adequately predict the spatial pattern of most soil properties deemed important in terms of generating field maps for a variable rate management system. Attempts to sample by topography would not improve the characterization of soil variability at these sites. However, some soil properties did display reasonably strong correlations with one another or with elevation. Thus, the potential for covariate analysis to possible improve spatial predictions of soil properties may exist, although these relationships need to be addressed on a site by site basis. Ultimately it is the spatial prediction of crop requirements, based on the crop response to applied inputs that will determine the success of variable rate management systems. Although yield data was not presented in this paper, on these sites we have found very little evidence that spatial patterns in crop yields are related to the measured soil test levels of N, P, K, Ca, Mg or pH. This in part may reflect the fact that the basic fertilization practices used by the farm cooperators masks much of the variability in soil fertility observed in these fields.

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Table 1. Number of samples (N), within field elevation changes (Z) and ranges of soil test P, K and pH measured at 18 field sites.

			Soil Test P (ppm)			Soil Test K (ppm)			Soil pH		
Site	N	Z (m)	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1	124	3.2	13	5	208	134	70	831	7.2	5.8	7.8
2	126	0.4	16	5	60	200	127	406	7.7	7.5	7.9
3	250	3.2	21	3	63	134	49	269	6.1	3.8	7.7
4	128	11.6	13	6	32	143	77	219	7.4	6.2	7.8
5	197	14.4	63	14	298	232	91	590	7.3	6.1	8.2
6	163	3.2	13	3	30	157	79	288	7.3	5.1	7.8
7	150	1.3	30	7	120	134	46	362	5.8	4.1	7.6
8	187	13.3	16	4	122	100	50	392	7.5	6.5	8
9	161	15.8	13	4	41	147	74	263	6	4	7.5
10	132	3.5	25	4	71	193	78	470	5.4	3.9	7.6
11	143	5	28	8	88	149	48	366	5.9	4.1	7.6
12	178	4.8	9	4	20	59	25	128	7.4	6.9	7.8
13	107	2.7	21	5	68	118	58	314	6.1	5.1	7.6
14	143	5.9	14	7	39	125	80	222	5.4	4	7.4
15	203	0.6	10	2	31	201	118	256	6.8	5.7	8.1
16	105	6.5	53	32	91	306	171	437	7.1	6.4	7.6
17	87	1.1	13	1	56	111	41	250	6.9	5	8
18	170	11.4	21	7	48	119	54	336	5.4	4.1	7.5

Table 2. Relative proportions of fields that would be under, over and properly fertilized if a constant fertilizer rate was applied based on the average soil test for the field.

Site	Phosphorus				Potassium			
	Mean value (ppm)	Over (%)	Under (%)	Proper (%)	Mean Value (ppm)	Over (%)	Under (%)	Proper (%)
1	13	3	77	20	134	0	64	36
2	16	14	57	29	200	0	0	100
3	21	17	23	60	134	0	37	63
4	13	0	52	48	143	0	27	73
5	63	0	18	82	232	0	8	92
6	13	0	48	52	157	0	16	84
7	30	40	9	51	134	0	47	53
8	16	9	64	28	100	30	51	29
9	13	4	58	38	147	0	32	68
10	25	29	22	49	193	0	6	94
11	27	26	9	64	149	0	38	62
12	9	34	44	22	59	39	38	23
13	21	22	22	56	118	41	42	17
14	14	3	45	52	125	0	50	50
15	10	17	58	25	201	0	1	99
16	53	0	0	100	306	0	0	100
17	13	6	60	34	111	36	42	22
18	21	16	19	65	119	41	35	24

Table 3. Variogram parameters for soil test P, K and pH for 18 study sites in Ontario.

Site	Phosphorus			Potassium			pH		
	C_0	C	Range (m)	C_0	C	Range (m)	C_0	C	Range (m)
1	0.02	0.317	73	0	0.25	128	0	0.135	43
2	0	0.43	38.5	0	0.04	39	0	0	0
3	0.09	0.287	79.2	0.065	0.111	64	0.396	0.786	55.6
4	0	0.106	44	0.003	0.046	55.5	0.003	0.047	37
5	0	0.166	61	0.019	0.108	70	0.071	0.271	111
6	0.072	0.272	70	0.06	0.083	216	0.08	0.41	90
7	0.052	0.225	56	0.047	0.218	140	0.165	0.825	49
8	0	0.272	46	0	0.174	104	0.04	0.08	125
9	0	0.2	73	0.019	0.1	58.5	0.156	0.916	109
10	0	0.39	28.8	0.05	0.075	73	0.33	1.154	72.7
11	0.008	0.575	192	0.072	0.203	93	0.072	0.794	42.8
12	0.064	0.147	63.8	0.04	0.45	860	0.012	0.022	35.4
13	0.217	0.439	161	0.045	0.136	41.7	0.084	0.264	38
14	0.02	0.087	98	0.01	0.04	32	0.254	1.484	423
15	0	0.174	28.8	0	0.02	63.9	0	0.32	44.4
16	0	0.057	31.3	0.03	0.07	200	0.019	0.13	258
17	0.569	1.421	97.4	0.05	0.18	35	0.271	0.968	31.8
18	0.027	0.196	94.4	0	0.082	34.3	0	0.35	32

C_0 - nugget variance
C - maximum variance

Table 4. Mean and ranges for soil parameters at different slope class positions for site number 3.

Slope Position	N	Soil Test P (ppm)			Soil Test K (ppm)			Soil pH		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
All	250	3	72	21	40	283	134	3.8	7.7	6.09
Upper Level	15	14	27	20	67	139	11	5.2	7.2	6.29
Diverging Shoulder	27	8	40	22	82	205	136	4.4	6.9	5.77
Converging Shoulder	12	12	33	24	92	212	149	5	6.3	5.77
Diverging Back	73	3	63	23	59	230	137	4.2	7.6	6.04
Converging Back	70	5	57	19	49	234	124	4.3	7.5	6.33
Diverging Foot	12	11	44	28	84	185	138	3.8	6.9	6
Converging Foot	27	8	41	23	75	269	144	4	7.3	6.11
Lower Level	14	5	34	15	88	224	140	3.8	7.7	6.03

Table 5. Ranges of Spearman Rank correlations for selected site parameters observed for the 18 sites.

	Soil test K	Soil test pH	Elevation	Organic Matter
Soil test P	0.17 to 0.89	-0.65 to 0.20	-0.67 to 0.69	-0.49 to 0.34
Soil test K	--	-0.50 to 0.19	-0.42 to 0.57	-0.46 to 0.20
Soil test pH	--	--	-0.80 to 0.59	-0.34 to 0.44
Elevation	--	--	--	-0.80 to 0.10

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