SPATIAL VARIABILITY OF SOIL FERTILITY FOR PRECISION AGRICULTURE[1]

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ABSTRACT

The objective of this study was to characterize the spatial variability of some soil fertility indicators to explain the variability of grain yield. The field is located at the ABC Foundation Research Center, in Parana State, Brazil. This region has very mild summer climate, ideal for no tillage. Under these conditions, soil fertility may be more limiting to grain yield than soil physical properties. Soil samples were collected at approximately 30 m square grid at 0-5, 0-10 and 0-20 cm depth and the coordinates of each of the 225 points were recorded with DGPS. The choice of sampling depths was to verify if any single depth is enough to inform soil fertility status under no-till. The properties analyzed are pH, H+Al, CEC, and sum of bases (SB). H+Al are soil acidity factors very important in tropical soils. Semivariograms showed a very strong trend indicating soil fertility gradient. The linear trend was removed to satisfy the intrinsic hypothesis. It was concluded that the soil fertility indicators have a very high variability, indicating that they may be responsible for the variability in grain yield.

INTRODUCTION

Grain production is becoming a very competitive agricultural activity because of the marketing pressures to produce at lower costs, and because of environmental requirements to produce without erosion and pollution. No tillage is being successfully used in order to avoid erosion in many parts of Brazil. In particular, in the Northeast part of the state of Paraná State, the mild climate favors this tillage system very well. The complex combination of higher imediate profit with less environmental damage has lead to a technology which is now called precision agriculture or site specific management (Schueller, 1992), through which the soil properties are managed according to their variability (Stafford, 1999). Depending on the scale that the field is sampled in relation to its size, spatial correlation may be shown as has been reported for many years (Burgess & Webster, 1980, McBratney & Webster, 1981, Vieira et al., 1983). When spatial correlation exists, any statistical analysis that requires independence fails and geostatistics becomes the appropriate tool (Oliver, 1999). Soil nutrient variability mapping has been reported as an important component for establishing management zones (Castrignanò et al., 2000), although there are reports on recommendations affected by time of sampling (Hoskinson et al., 1999) and by variability in laboratory results (Brenk, et al. 1999). The knowledge of the spatial variability using the appropriate statistical tools is, therefore, essential for mapping and

[1] This work is being partially supported by FAPESP (São Paulo State Research Foundation).

delineating management zones and, consequently, for the application of precision agriculture techniques.

The objectives of the present study were to characterize the spatial variability of some soil fertility indicators and to explain the variability of grain yield.

METHODS

The experimental field is located at the ABC Foundation Research Center, in Parana State, Brazil. This region is characterized by a very mild summer climate which allows for application of no tillage cropping system. Under these environmental conditions, soil fertility may be more limiting to grain yield than soil physical properties. This is the very first stage of data analysis on this project as the soil physical analyses are not ready. Soil samples were collected on an approximately 30 m square grid at 0-5, 0-10 and 0-20 cm depth and the coordinates of each of the 225 points were recorded with DGPS. Soil fertility analyses was made on these samples and the properties analyzed here were pH, H+Al, CEC, and Base Saturation percentage. The choice of the three depths of sampling was based on the fact that no tillage system tends to favor accumulation of some nutrients at the surface. For this reason, the ideal depth of sampling to characterize the spatial variability is as yet not known.

Spatial variability was primarily evaluated through semivariogram calculation, graphing, model fitting and comparison for each variable (Burgess & Webster, 1980). The intrinsic hypothesis of geostatistics requires that the semivariograms must have a sill, otherwise it indicates that the data have a trend in some direction (Vieira et al., 1983). Because a strong trend was found in all semivariograms, a linear trend was removed from all the data by fitting a linear trend surface, subtracting it from the original data and working on the residuals. The choice of linear surface and not any other was because it was the simplest surface that would remove the trend. The linear trend surface was added back to the residuals after kriging estimation in order to produce soil fertility maps.

RESULTS and DISCUSSION

Table 1 shows the general statistics parameters for the variables under study on the 3 depths sampled. For pH, H+Al and for CEC, the change in mean values as the thickness of the layer sampled increased from 5 to 20 cm, was not too big. However, for Sum of bases (SB) there was about 40% decrease in the mean values. The reason for this is probably due to the concentration of nutrients near the surface since the field is cultivated using no-till. The coefficients of variation are all, in general, medium to low. For the 0-10 cm samples, there was a decrease in the coefficients of variation of all variables, except for SB that had a slight increase. Curiously, for the 0-20 cm samples the CVs increase again. It is possible that the depth of placing fertilizer changes within the field and 0-10 cm samples this zone more efficiently than the 0-5 cm. The coefficients of skewness and kurtosis indicate that as the depth of sampling increases, SB and CEC tend to depart from the normal distribution while pH and H+Al approach it.

The parameters for the semivariograms fitted are shown in table 2, for all three depths sampled. The column named WSSD is the Weighted Sum of Squared Deviation of the fitted model to the experimental semivariance values. The purpose for this parameter is to express some estimation of the goodness of fit for the model, where the smaller the value the better the fit. A perfect fit would have a WSSD equal to zero. All semivariograms were fitted with spherical model. The column that has the continuity ratio $CR=C_0/(C_0+C_1)*100$, expresses the proportion of the nugget effect to the sill, i.e., the amount of spatial dependence at small distance relative to the total variability. Obviously, the smaller the value of this relation, the higher the point to point continuity. For pH and for H+Al, as the depth of sampling increased, the CR value also increased, which, therefore, indicates that pH and H+Al change with depth, since as the depth of sampling increases, the small scale variability also increases. This is probably due to the no-till that causes increase in acidity near the soil surface. This is even more evident for pH than for H+Al, in particular from 0-5 cm to 0-10 cm. For sum of bases (SB) and cation exchange capacity (CEC) the reverse happened, i.e., there was a decrease in CR as the depth of sampling increased. This indicates that, with respect to these properties, the soil gets more point-to-point continuity with depth. The range of correlation, *a*, did not follow this trend since it decreased sharply from 0-5 cm to 0-10 cm, and then it increased back at 0-20 cm.

The distinct spatial behavior for pH and H+Al when compared to SB and CEC can be better seen in the graphs of the semivariograms shown in figure 1. The experimental values for the semivariograms for pH and for H+Al grouped much closer to the models fitted than the ones for sum of bases (SB) and for cation exchange capacity (CEC), as it was already indicated by the corresponding Weighted Sum of Squared Deviations (WSSD), shown in table 1. The semivariograms for SB and CEC showed a drastic shortening of the correlation range for the 0-10 cm depth of sampling when compared to the other two depths.

From the contour maps for the four variables analyzed for the three depths of sampling shown in figure 2, the reason for the linear trend found in the data can be seen. All four variables have a very defined gradient towards the left-hand side of the field, except for the surface layer in which this effect is somewhat diffuse. This left-hand side of the field has the lowest pH values, the highest H+Al values, the lowest SB values and the highest CEC values. Therefore, if the grain yield maps also show a decrease towards the left-hand side it will be an indication that soil fertility is the major factor affecting them. Otherwise, if the yield maps show different variability, then the causes of variability are others but not soil fertility. The three depths of sampling seem to be for very different populations because the variables analyzed are stratified by depth. Therefore, as far as the characterization of the spatial variability of the variables analyzed, neither one of the depths of sampling is better than the other for no-till system.

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TABLE 1. General statistical parameters for original data

Variables	Mean	Std.Dev.	C.V.	Minimum	Maximum	Skewness	Kurtosis
				0-5cm			
pH	5.56	0.55	9.88	5.00	7.00	0.51	2.04
H+Al	46.88	18.30	39.02	15.00	98.00	0.43	2.44
SB	101.00	26.25	26.00	47.00	182.00	0.56	3.34
CEC	147.90	18.83	12.73	112.00	202.00	0.45	2.77
				0-10cm			
pH	5.24	0.41	7.84	4.50	6.40	0.57	2.83
H+Al	58.78	19.96	33.95	20.00	98.00	0.04	2.06
SB	77.41	22.02	28.44	30.20	183.40	0.92	5.21
CEC	136.20	16.64	12.22	94.20	208.40	0.53	4.49
				0-20cm			
pH	5.10	0.24	9.54	4.30	6.70	0.80	3.21
H+Al	68.41	610.50	36.11	20.00	150.00	0.55	2.95
SB	62.83	439.60	33.37	24.20	160.90	0.92	4.66
CEC	131.20	487.20	16.82	85.80	203.70	0.81	3.54

TABLE 2. Parameters for semivariogram models fitted

Variable	Model	C_0	C_1	a	CR[1]	WSSD[2]	Variance
			0-5cm				
pH	Spherical	0.02	0.10	210	16.67	2.04	0.1065
H+Al	Spherical	40.00	70.00	195	36.36	66.30	102.70
SB	Spherical	380.00	170.00	300	69.09	1418.06	545.10
CEC	Spherical	250.00	93.00	300	72.89	680.21	343.50
			0-10cm				
pH	Spherical	0.03	0.10	210	23.08	3.33	0.1199
H+Al	Spherical	90.00	120.00	195	42.86	259.06	200.00
SB	Spherical	200.00	190.00	140	51.28	929.30	412.50
CEC	Spherical	125.00	100.00	100	55.56	278.55	237.40
			0-20cm				
pH	Spherical	0.03	0.08	240	23.81	1.27	0.0997
H+Al	Spherical	125.00	120.00	150	51.02	256.26	236.50
SB	Spherical	200.00	190.00	250	51.28	1370.31	406.20
CEC	Spherical	200.00	100.00	250	66.67	519.36	301.70

[1]CR= $C_0/(C_0+C_1)*100$; WSSD = Weighted Sum of Squared Deviation

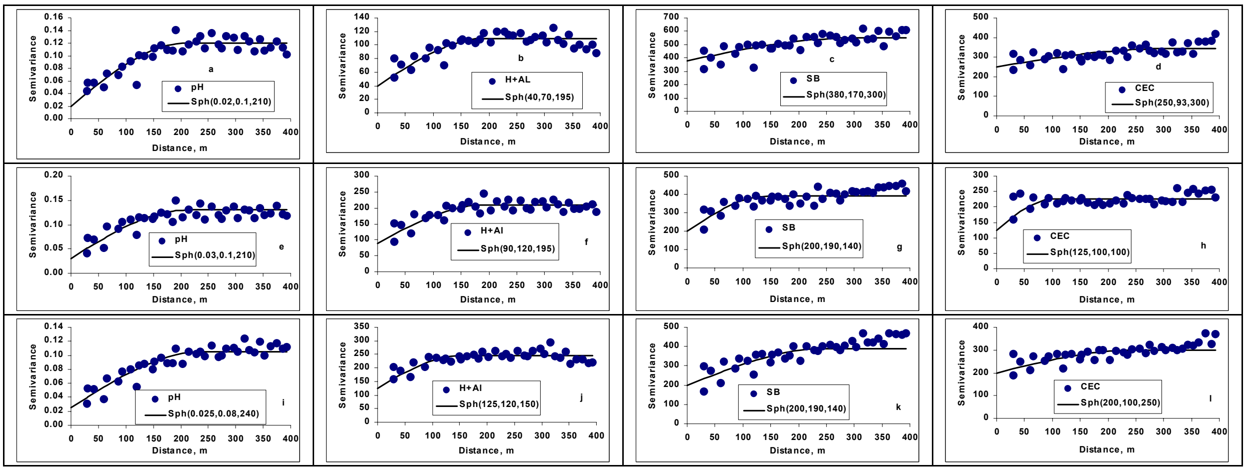

Figure 1. Semivariograms for pH, H+Al, Sum of bases and CEC in the 3 depths sampled.

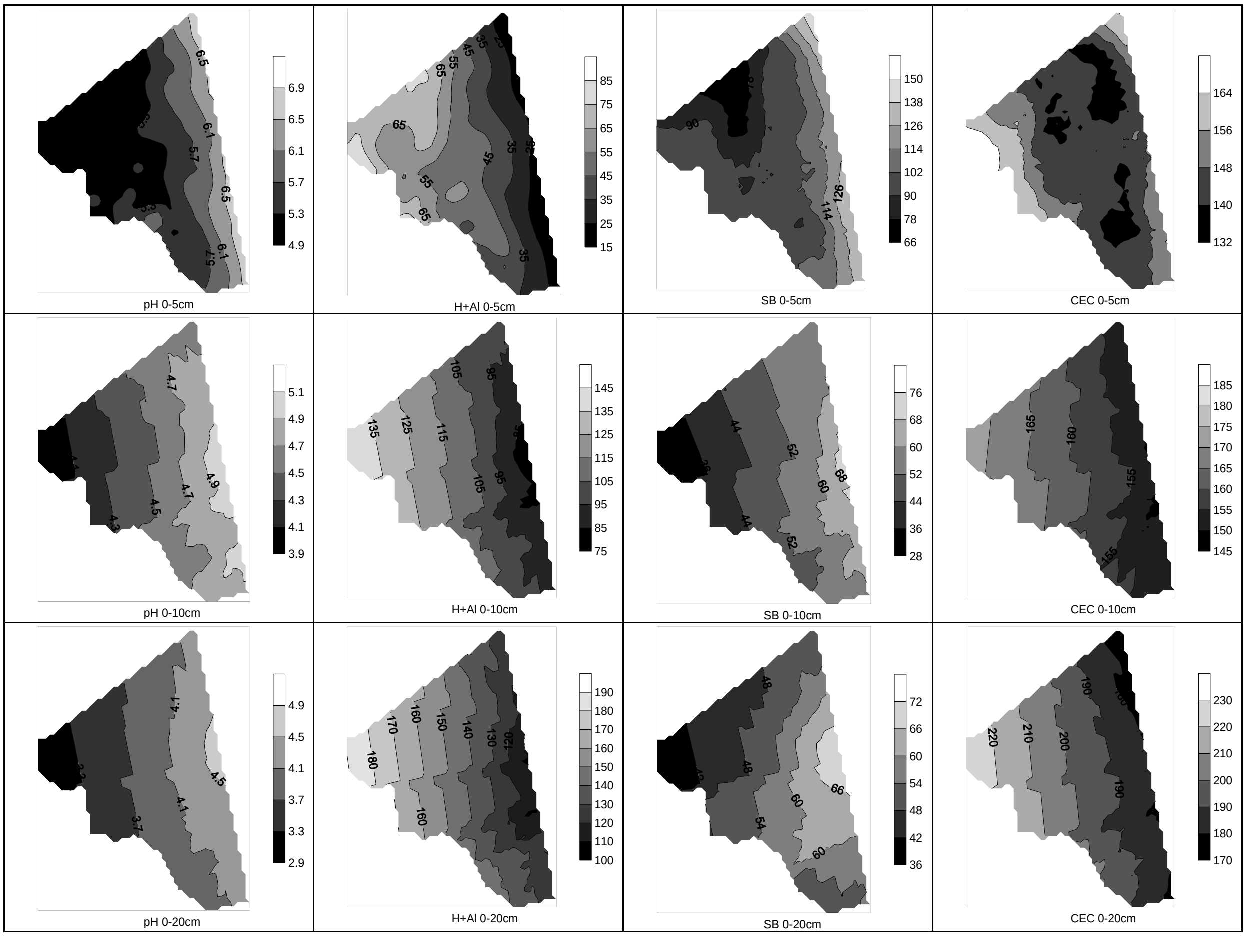

Figure 2. Contour maps for pH, H+Al, Sum of bases and CEC for the 3 depths sampled.