Assessment of the spatial relationship between soil properties and topography over a landscape

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Abstract

The objective of this study was to assess the spatial relationships between soil properties and topography over a watershed cultivated with sugarcane. Soil samples were collected at 0-20cm depth from 244 data points approximatelly evenly distributed over the entire watershed. The coordinates of the sampling points were recorded with a DGPS. In each sampling point, average topographic height, slope and aspect were calculated from the digital elevation model in a GIS environment. Soil samples were analysed for physical and chemical routine characterizations. The spatial dependence of each individual variable as well as the relationship between them were evaluated with semivariogram and cross semivariograms. Soil phosphorus and calcium showed extremelly high variability owing to the variety of soil types and depths over the watershed. All variables studied were spatially dependent. There was spatial dependence between slope percentage and total sand, natural clay, phosphorus, calcium, cation exchange capacity and bases saturation. A positive correlation was characterized between slope and total sand and a negative one between slope and the other five variables. These results indicate the possibility to map those properties using cokriging with slope as the auxiliary variable.

Key Words

Terrain slope, topographic variables, semivariogram, cross semivariogram

Introduction

Depending upon the scale of the measurements and the complexity of the environment from which the data are collected, classical statistics fails to represent the data. In most of these situations, geostatistics is the appropriate tool to describe the spatial variability and the relationships between data. It is generally recognized that soils can vary widely as a function of their position on the landscape, parent material variability, erosion history, and cultivation. The amount of variation over an area depends on many environmental conditions and how they have been acting on soil properties over time. Spatial variability of soil properties has been long known to exist and has to be taken into account every time field sampling is performed. Beckett and Webster (1971) presented a very comprehensive review with deep discussion of soil variability on soil chemical properties. Soil variability can also occur as a result of agricultural management, land use and erosion (Vieira, 2000). Ceddia *et al.* (2009) related some soil physical attributes with topography over a landscape and concluded that it was viable to use cokriging with topography as an auxiliary variable to map sand, clay and water retention parameters. The objective of this study was to assess the spatial relationships between soil properties and topographic attributes over a watershed cultivated with sugarcane. The fundamental assumption is that mapping soil properties using auxiliary variables may help to understand the processes occurring over a landscape and improve the precision of the constructed maps.

Material and Methods

The experimental area is located on a watershed named Ceveiro near Piracicaba, SP, Brazil. Soil samples were collected at 0-20cm depth from 244 data points evenly distributed over the entire wastershed. The coordinates of the sampling points were recorded with a DGPS, and their position within the watershed are shown in Figure 1. In this figure, the symbol code classification represents the average topographical height or altitude according to five classes of equal number. Average topographic heights or altitudes (m), slopes (% and degrees) and aspects (degrees) were calculated from digital elevation model in a GIS environment having as feature definition image the sampling points. Soil samples were analyzed for physical and chemical routine characterizations. The spatial dependence of each individual variable as well as the relationship between them were evaluated with semivariogram and cross semivariograms. A total of twenty-nine soil and topographic variables were analysed.

The Geostatistical Approach

The spatial dependence of soil properties, according to Vieira *et al.* (1983), can be evaluated by examining the semivariogram. If the semivariogram increases with distance and stabilizes at the a priori variance value, it means that the variable under study is spatially correlated and all neighbours within the correlation range can be used to interpolate values where they were not measured. Moreover the spatial relationship between variables can be evaluated using the cross semivariogram. Semivariogram modeling is the foundation for geostatistical analysis, and can also be the most difficult and time consuming portion of the analysis. In part, this is due to the computationally intensive calculations, but it is also due to the difficulty in defining semivariogram models which reasonably honor the experimental semivariograms (McBratney and Webster, 1986). The models fitted are described by the parameters C_0, which express the nugget effect, C_1, the structural variance, and a, the range of spatial dependence. In this work, the models were fit by using least squares minimization and judging the coefficient of determination. Whenever there was any doubt on the parameters and model fit, the jack knifing procedure was used to validate the model, according to Vieira (2000).

Results and discussion

The descriptive statistical parameters for ten soil and topographic variables which showed spatial correlation between pairs are illustrated in Table 1. It can be seen that most of the variables express an extremely high variability. The highest of all is for phosphorus content (P) with a CV of 335%. Obviously that depends on the dimension of the area under study. Ceddia *et al.* (2009) have found 65% for clay content on a 2.64ha field, although Siqueira et al. (2008) have found 35% for clay content for a 3.52ha field in. These results indicate that the terrain variability depends not only on the field size but also in the sampling intensity with respect to the size. The obtained semivariograms for topographic variables (Figure 2) revealed that for four studied variables data were best fit by the exponential model. The range, which marks the limit of spatial dependence, is around 180m for slope, 900m for aspect, and 1,700.00 for altitude. On Figure 3, semivariograms for the soil variables show that range varies around 2,000m for six studied variables. The best fits were obtained for total sand ($R2= 0.9725$), natural clay ($r2=0.9468$), and base saturation ($r2= 0.9120$). The semivariograms for phosphorous (P), calcium (Ca), and cations exchange capacity (CEC) were adjusted employing the spherical model. The poorer adjust was for P ($r2=0.4589$), followed by Ca ($r2= 0.7909$) and CEC ($r2=0.8563$). The cross semivariograms revealed a positive correlation between total sand and slope, which could be related with the occurrence of Ultisols and Alfisols on the highest altitudes at the northern and northwestern borders of the watershed, as described by Weill & Sparovek (2008). The four chemical variables, P, Ca, CEC, and base saturation (V) have showed a negative correlation with slope. This is related with the fact that shallower soils, like Entisols and Inceptisols, which maintain a major influence from the parent material, occur at more gentle slopes in Ceveiro watershed. Moreover, the tendency to bases accumulation in the lower part of the hillside is also known. In relation to the natural clay, the negative correlation with slope could be due to the fact that in the watershed the soil as a whole and the sandy topsoil of the Ultisols and Alfisols are deeper and the textural gradients tend to be higher as the slope declines.

Conclusions

The geostatistical approach could enhance the comprehension of some processes occurring over the Ceveiro watershed. Some soil properties could be mapped using cokriging with slope as the auxiliary variable.

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Table 1. Descriptive statistics for topographic and soil variables in Ceveiro watershed.

Variable	Mean	Variance	C.V.	Minimum	Maximum	Skewness	Kurtosis
Altitude	508.70	646.60	5.00	464.10	582.50	0.659	0.046
Slope (%)	10.21	39.00	61.15	0.00	35.36	0.812	0.814
Slope (degrees)	5.81	12.31	60.42	0.00	19.47	0.757	0.624
Aspect (degrees)	169.60	9614.00	57.81	0.00	355.5	-0.258	-1.062
Total sand (%)	61.12	554.00	38.51	11.00	94.00	-0.605	-1.091
Natural clay (%)	12.36	102.20	81.82	0.00	46.00	1.074	0.183
P (mg kg^{-1})	15.69	2777.00	335.80	1.00	770.00	12.26	172.50
Ca (mmol$_c$ kg^{-1})	27.54	801.00	102.80	1.00	205.00	2.175	7.079
CEC (mmol$_c$ kg^{-1})	78.87	2184.00	59.25	12.80	246.50	1.268	1.261
V (%)	43.91	437.20	47.62	6.00	96.00	0.465	-0.654

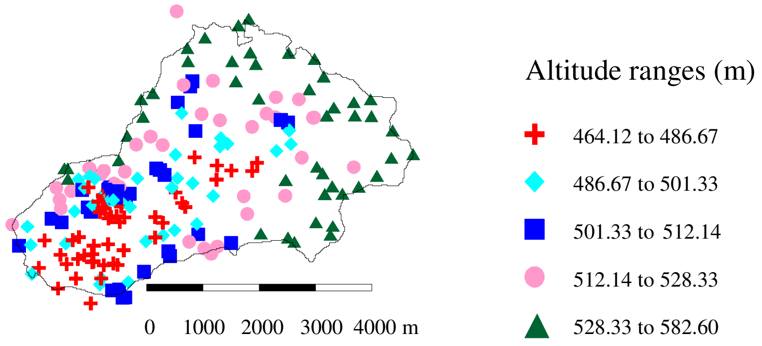

Figure 1. Location of sampling points within the Ceveiro wastershed (SP, Brazil) with topographic height.

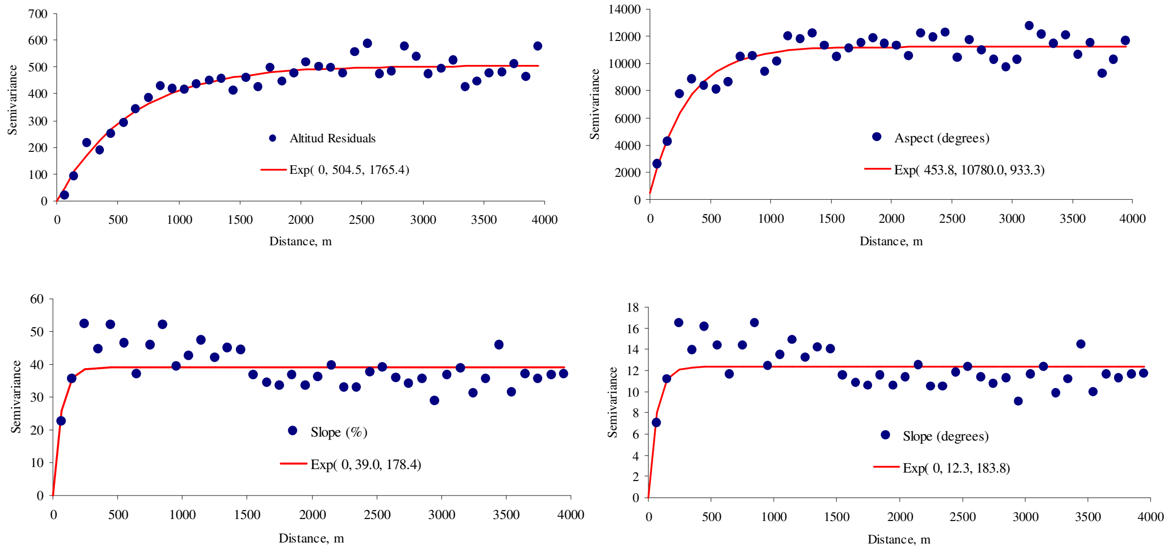

Figure 2. Semivariograms for the topographic variables: altitude residuals, aspect, and slope.

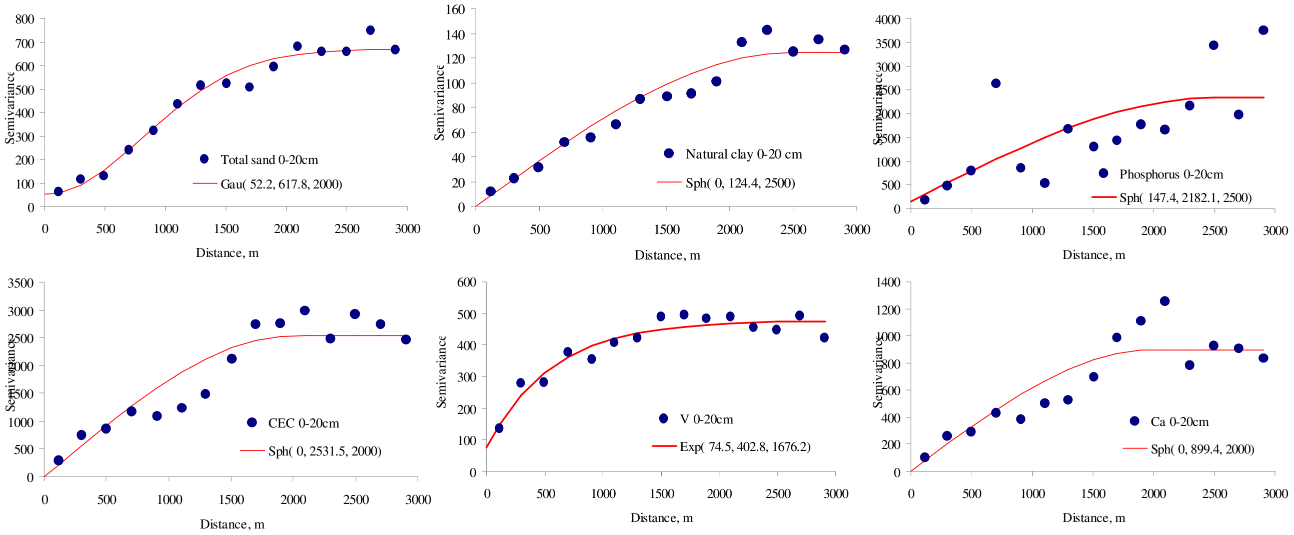

Figure 3. Semivariograms for soil variables: total sand, natural clay, phosphorus(P), calcium(Ca), cation exchange capacity (CTC), and base saturation (V).

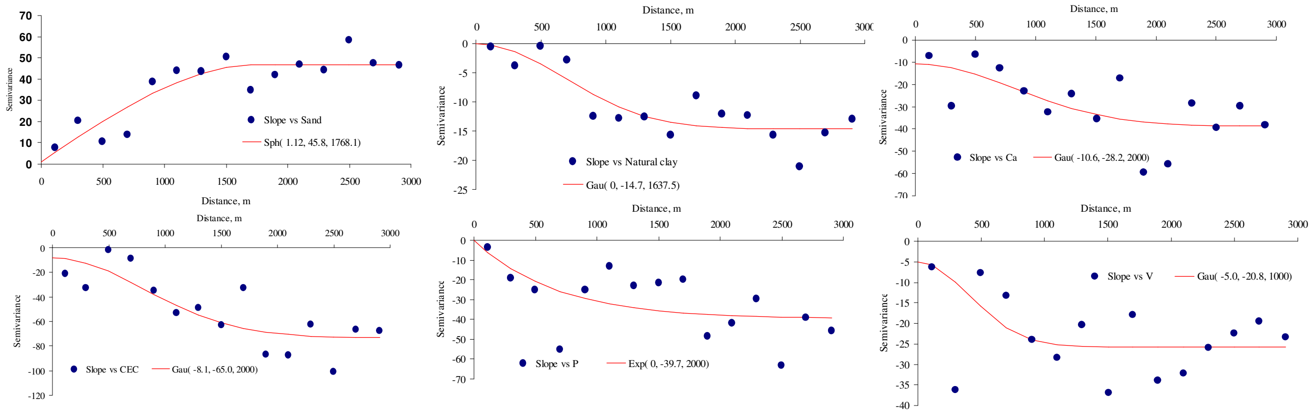

Figure 4. Cross semivariograms between slope and soil properties.