EXPLORING THE MULTIVARIATE SPATIAL STRUCTURE OF SOIL ACIDITY DATA.

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SUMMARY

On an attempt to explore the multivariate spatial structure of soil acidity data, the variables Calcium (Ca), Magnesium (Mg), active acidity (pH) and potential acidity (H+Al) were measured by 204 soil samples collected 0-20 depth from a 60 m regular grid on a corn/soybeans crop at Araguari-MG, Brazil. They were chemically analyzed as well. Under scope of Linear Model of Corregionalization (LMC), direct and cross variograms were modeled with a nugget effect and a spherical model at 451,28 m range, analyzing corregionalization structure range among soil acidity variables, in parallel with Principal Component Analysis (CPA). This analysis captured acidity phenomena structure in micro scale (nugget effect) with the influence divided between Ca and Mg elements and pH of this soil, given by an intense agronomical handling which was submitted to the soil over the years. On a long range the phenomenon was explained by H+Al, given by the geological influence (pedological formation). The eigenvalues of the structures modeled given by PCA show that nugget effect is an important part of the model. The model proposed estimated by cokriging was filtered, once interested on long range variability. The filtering process removes high frequencies provide by nugget effect, resulting in a more continuous map of the acidity phenomenon on this soil.

INTRODUCTION

Soil acidity is a frequent problem in tropical soils, which affects major agricultural crops. The main effect of high acidity is the availability of Aluminum (Al) on soil, which is toxical to plants. Aluminum represents a serious problem in natural acid soils and in soils acidified by human activity. Much attention has been paid to the determination of the content of labile aluminum forms on soil, and pH is generally the most important factor controlling aluminum solubility and mobility. However, simple practices like lime application can solve that question, making Al unavailable to roots, besides providing Calcium (Ca) and Magnesium (Mg) to plants. A lot of factors interfere in this process, by soil handling (human factor) or by soil type (pedological factor). Some factors which govern soil variations have a short range action, whereas other factors operate at longer distances. As a consequence, soil variables are expected to be correlated in a way that is scale dependent (Castrignanò et al. 2000). The method called Factorial Kriging Analysis (FKA) was developed by Matheron (1982) and enable to modeling the correlations among the soil physical and chemical properties at each of the different spatial scales. This work had as objective study the spatial variability of soil acidity at a precision farming field in central Brazil and search plausible explanations for their distributions among different scales.

CASE STUDY

The area studied covers 71,79 ha of a rural property at Araguari-MG, Brazil (Figure 1), coordinates 18o 40' S latitude and 48o 15' W longitude, in which corn and soybeans are cultivated under rotation system. Details about soil type, climate, vegetation and topography are present in Manzione (2002). Georeferrenced samples were taken allow a known 60 m square grid, performing a total of 204 soil samples collected 0-20 depth (Figure 2). Chemical parameters were measured on soil samples and analyzed according to Embrapa (1997). Ca, Mg, pH and H+Al was chosen for their associated behavior under handling practices, like liming or from original soil acidity, like parental material. Factorial Kriging Analysis (Matheron, 1982) was performed on ISATIS software (Geovariances 2003). The three steps developed in FKA are the following:

1. Modeling the coregionalization of the variables using linear model of coregionalization (LMC). The $p(p+1)/2$ experimental direct and cross-variograms are modelled as linear combinations of the same set of N_s basic variogram functions $g_u(\mathbf{h})$.
2. Analyzing the correlation structure between variables applying principal component analysis (PCA) to decompose the coregionalization matrices $\mathbf{B}_u$ into matrices $\mathbf{A}_u$ and to summarize relation between variables.
3. Estimating and mapping the regionalized factors and variables. The behaviour and relationships between variables at different spatial scale can be illustrated by mapping the regionalized variable $Z_i(\mathbf{x})$, the spatial components $(\mathbf{x})$, and the regionalized factors $(\mathbf{x})$. In each case the estimation is performed by cokriging. pH variable was chosen to discuss filtering procedure taken into account their relation with Aluminum availability on soil. For the authors this consists on an important layer on agro-ecological GIS projects. Factorial Kriging Analysis was also applied in order to filter out some covariance or drift components of the model, in order to remove high frequencies (nugget effect) or even low frequencies (long range) at the proposed model. Operations with vector and raster results and map visualizations were performed on SPRING GIS (Câmara et al. 1996).

Fig. 1. Experimental field at Araguari(MG)-Brazil

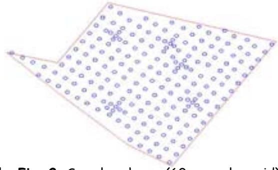

Fig. 2. Sample scheme (60m regular grid)

RESULTS AND DISCUSSIONS

Under scope of Linear Model of Corregionalization (LMC), direct and cross variograms were modeled with a nugget effect and a spherical model at 451,28 m range, analyzing corregionalization structure range among soil acidity variables, in parallel with Principal Component Analysis (PCA).

A first visual inspection of the variograms and cross-variograms suggested the presence of three basic components at different spatial scales. The first observed structure was pure nugget effect due to measurement errors and micro-variation within the smallest sampling interval 60 m. The second structure reflected a transitive process of plot-size range, approximately of 100 m. The third structure seemed unbounded at the scale of study; it could be represented either by an unbounded variogram or by a transitive model with a longer range, approximately from 400 m. In this case PCA analysis reveal that this structure didn't have great contribution to coregionalization model, and only nugget effect and a spherical model at 451,28 m remains at the model. Adjusted direct and cross variograms are on Figures 3.

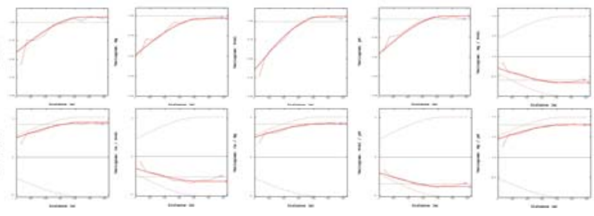

Fig. 3. Direct and cross variograms modeled for Ca-Mg-pH-H+Al.

The product-moment correlation coefficient did not reveal the real relationships among the variables, since it averages out distinct changes in the correlation structures occurring at different spatial scales (Castrignanò et al. 2000). The values of *buij* were used to calculate the structural correlation coefficients for each basic structure adjusted (Goovaerts 1992, Borůvka and Kozák 2001), and are presented at Table 2. Most of the calculated structural correlation coefficients were higher than correlation coefficients at Table 1, which means that a large part of the relationship between variables was spatial-based. Given by example pH and H+Al structural correlation coefficients, they were -0,925 at first structure and -0,6202 at second structure. This decrease of correlation could be explained by both variables have a similar covariance function at nugget effect and at spherical model H+Al had a stronger covariance function than pH.

Table 3. Structural correlation matrices for each spatial scale.

Nugget effect	Ca	H+Al	Mg	pH
Ca	1	-	-	-
H+Al	-0,6851	1	-	-
Mg	0,9025	-0,6814	1	-
pH	0,9004	-0,9250	0,8522	1
Spherical model	Ca	H+Al	Mg	pH
Ca	1	-	-	-
H+Al	-0,5832	1	-	-
Mg	0,7357	-0,6452	1	-
pH	0,8146	-0,6202	0,7529	1

Structural correlation coefficients could reveal correlations for each spatial scale modeled. Also the estimation of the structural correlation coefficients seems to confirm the nugget influence in the model. Nugget effect always comprises an unknown variance caused by procedural errors.

Geostatiscal analysis combined with PCA analysis allowed discrimination of soil sources of variability at each scale modeled. The factors resulting from PCA analysis represents a synthesis of the information provided by the individual variables.

This analysis captured acidity phenomena structure in micro scale (nugget effect) with the influence divided between Ca and Mg elements and pH of this soil, given by an intense agronomical handling which soil was submitted to over the years. The first two factors at short range explained more than 97% of the overall variation at this spatial scale. On a long range the phenomenon was explained by H+Al, given by the geological soil influence (pedological formation). The first two factors of the spherical model structure explained more than 90% of the overall variation at this spatial scale. The eigenvalues of the structures modeled given by PCA confirm that nugget effect is an important part of the model, and that the sample scheme didn't captures small variations presented on this soil. The spatial interrelations among the variables, as described above by coregionalization matrices for each structure, can be clearly displayed in the plots of correlations corresponding to different spatial scales (Goovaerts, 1992; Castrignanò et al., 2000). At nugget effect structure, pH and H+Al had a strong correlation, which was no so important at the second structure, where pH had strong correlations with Ca and Mg. The spatial continuity of H+Al had a strong influence at second structure, and made pH establish a cluster with Ca and Mg values. Figure 4 presents the pair of coordinates of each variable, determined by the pair of correlation coefficients between your spatial component and the first two regionalized factors.

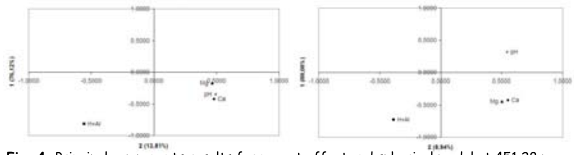

Fig. 4. Principal components results for nugget effect and spherical model at 451,28 m.

The model proposed estimated by cokriging was filtered, once interested on long range variability. This procedure allow visualize only interest features, removing discontinues individually, enhancing long range variability of the phenomenon, and showing the drift contained on the model. pH results of filtering the nugget effect structure, the spherical model structure and the drift part of cokriging maps are present on Figure 5, 6 and 7.

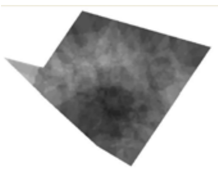

Fig 5. Cokriged map for pH with spherical model filtered.

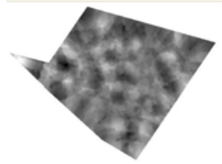

Fig 6. Cokriged map for pH with universal drift filtered.

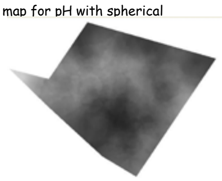

Fig 7. Cokriged map for pH with nugget effect filtered.

Sources of intense handling affect intensely the variation on topsoil (0-20 cm). The soil over the studied area has been subjected for intense soil operations over the years. Practices like tillage and plough have a nominal range at soil relative of used implement (plow, harrow, subsoilers). It causes topsoil desegregation, inversion and pulverization of the soil sod and variations which a grid of 60 square meters didn't capture, resulting in a nugget effect which has an important influence in the model. The filtering procedure treated this problem removing high frequencies signaled by nugget effect, and resulting in a more continuous map of the acidity phenomenon on this soil. This procedure could treat problems at sample scheme, removing the nugget effect, and enhancing spatial continuity of the acidity phenomena. Without the drift part, the presence of local variation is clearly, confirming the choice to remove the nugget and consequently give a global mean effect on the final map.

CONCLUSIONS

Multivariate geostatistical analysis has allowed separating the different sources of spatial variation at different scales. This method has offered ways for formulating hypotheses about the probable sources of soil variation, resulting in a better understanding of the variations within the study area would allow more sophisticated land management to be developed. FKA approach has been demonstrated to be a highly effective method to separate the area into homogenous zones in order to optimize their management. Spatial distribution of soil properties in this context is influenced by many factors and the geostatistical approach is a useful tool to understand the dynamics of addition/removal of soil attributes. Filtering procedure enhance spatial scales, separating their effects on final map results and removing noise at high frequencies. That is a possible way to treat problems like discontinuities resulted by sample schemes or nugget effects. These techniques have great potential to explore phenomena over chrono and toposequences, landscapes, watersheds and drainage basins.