Spatial Variability of Soil Physical Attributes in Machadinho d'Oeste (RO), Amazon Basin

Valladares, G.S.[1*]; Grego, C.R.[2;] & Batistella, M.[1]

[1] *Embrapa Satellite Monitoring, Av Dr. Júlio Soares de Arruda, 803, Pq São Quirino, 13088-300, Campinas-SP, Brazil.*
[2] *Agronomic Institute of Campinas, Av. Barão de Itapura, 1481, caixa postal 28, 13020-902 Campinas, SP, Brazil*

Abstract

The aim of this paper was to understand the spatial variability of soil physical attributes within the superficial layer (0-10 cm) in an area of agricultural colonization in Machadinho d'Oeste (RO). The attributes analyzed were real density, clay, silt, coarse sand, and fine sand contents. In September, 2004, 76 samples were collected through an irregular sampling strategy, based on soil and topographic features. Oxisols and Ultisols are the predominant soil types in the area. The clay content ranged from 2 to 67%, silt from 2 to 63%, coarse sand from 4 to 78%, fine sand from 6 to 45%, and real density from 2.08 to 2.60 (g cm^{-3}). Some of the high contents of silt can be due to resistant aggregates of the clay fraction, as the adopted methodology did not separate clay grains. The majority of attributes presented coefficients of variation higher than 40%, except for real density. Real density is highly correlated with the coarse sand fraction (r = 0,94) and with the sum of the clay and silt fractions (r = -0,86). Geostatistics was used to understand the spatial variability of such attributes, through the analysis of semivariograms, kriging, and isoline maps. Despite statistical distances among the samples, the spatial dependence ratio (RD) was classified as moderate and strong. The spherical model had good adjustment for the studied attributes. Similarities were found for the spatial behavior of some attributes, such as clay, coarse sand, and real density. The lowest range values were for clay, silt, and coarse sand (i.e., around 10,000 m). For fine sand and real density, the range was between 15,000 and 16,000 m. Kriging techniques were suitable to depict the space distribution of the studied attributes. Soils with clay contents higher than 30% are predominant in the area, followed by soils with loam texture.

1. Introduction

Information about the spatial variability of soil attributes is required for planning sustainable agricultural practices, particularly in recently deforested areas of the Amazon. Such information is needed for the management of agricultural systems as well as for soil conservation (Cerri et al., 2004). Pedogenesis governs the natural spatial variability of soils (Trangmar et al., 1985). But human activities can alter such properties (Paz-González et al., 2000; Valladares et al., 2005). Thus, spatial data are fundamental in land-use planning.

Many articles have used geostatistics techniques to evaluate the spatial dependency, the variability, and the spatial distribution of soil attributes in different scales (White et al., 1997; Vieira, 2000; Facchinelli et al., 2001; Carvalho et al., 2003; Cerri et al., 2004; Grego & Vieira, 2005). Cerri et al. (2004) tested the eficiency of such techniques to analyze the spatial distribution of soil attributes in the State of Rondônia.

The spatial location of the samples reveals patterns related to the soil attributes within the study area (Vendrusculo, 2001). The level of detail of the analysis depends on the distance

* Corresponding author. Tel: +55-19-3256-6030; Fax: +55-19-3254-1100
E-mail address: gustavo@cnpm.embrapa.br

between the sample points, the attribute to be analyzed, and the scale of the analysis (Grego & Vieira, 2005).

The objective of this research was to evaluate the spatial variability of physical properties of soils using geostatistics techniques for the analysis of data acquired in northeastern Rondônia, Brazilian Amazon.

2. Material and Methods

The study area is located in the municipalities of Machadinho d'Oeste and Vale do Anari, RO, between the coordinates 9º15' and 9º48' South and 61º48' and 62º30' West. The area is part of the Machadinho River watershed, tributary of Machado or Ji-Paraná River. Geology is characterized by materials of different periods. Mesoproterozoic –Intrusive Suite Serra da Providência, characterized by amphibole-biotite monzogranite, biotite monzogranite, biotite sienogranite, charnockites, mangerites and basic rocks. Paleoproterozoic-Mesoproterozoic – Complexo Jamari, with predominance of gneiss of granite and granodiorite composition, ancillarily dioritic, quartz-dioritic e tonalitic, less occurrence of anfibolites, and intermediate to basic rocks. Cenozoic – Immature Laterites or cemented and Sedimentary cover of the Quaternary (Bacci, 2005).

Topographical variation is due to dissection with slopes and ridges, reaching elevations higher than 200m. Between 100 and 200m, there are occurences of flatten surfaces with dendritic drainage and slopes, related to the interplateau depression (Embrapa, 1982).

Natural vegetation is dominated by upland and lowland equatorial forests. Climate is characterized by an average annual minimum temperature above 18ºC, and it is classified as Am according to Koeppen's classification scheme; June and July are the dryest months and the average annual precipitation is above 2000mm (Embrapa, 1982).

As a function of the lithological diversity and topographical conditions, soils show great variations in their morphological, physical, chemical, and mineralogical properties. (Valladares et al., 2003). In ridges under the influence of intermediate or basic rocks, nitossolos vermelhos eutróficos dominate, with lower occurence of nitossolos háplicos, latossolos vermelhos and vermelho-amarelos distróficos, well-drained and deep soils, with predominance of clay texture. In the interplateau depressions, in environments still dissected with topography of flatten tops or in slopes draining to water courses, there are the predominant soils within the study area, latossolos amarelos distróficos, acid and with high aluminum saturation. Soils formed of laterite imature, when presenting iron oxides in their profile, are classified as latossolos or argissolos plínticos (in the fourth categorical level) or even as plintossolos argilúvicos and pétricos. These soils are more common in inferior and medium thirds of slopes where iron oxides occur, however they also can occur in flatten relief, where latossolos predominate with a lower occurrence of yellow argissolos. In alluvial terraces nearby streams, in a hydromorphic environment, formed of Quaternary sediments, gleissolos háplicos predominate, but melânicos.also occur. In the Machadinho river valley, gleissolos háplicos distróficos plínticos are common, where the plíntico horizon occurs below the control section and the glei horizon. In Embrapa's map, these soils were classified as plintossolos (Embrapa, 1982).

Deformed samples were collected in 76 georeferenced sites between 0 a 0.10 m deep. The following attributes were determined: particle density, coarse sand, fine sand, silt, and clay contents. The used analytical techniques followed methodologies described in Embrapa (1997).

Geostatistics techniques were used to verify the spatial dependence of the variables, to interpolate data, and to produce maps (Vieira, 2000). Semivariograms were built based on the assumptions of the intrinsec stationarity hypothesis and the semivariance calculation γ(h), estimated through Equation 1:

$$\gamma^{*}(h) = \frac{1}{2\,N(h)}\sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \qquad \text{Eq. 1}$$

Where N(h) is the number of pairs of measured values Z(xi) , Z(xi+h), separated by a vector h. According to Vieira (2000), it is expected that measurements located nearby be more likely than those separated by large distances, i.e. that γ(h) increases with the distance h up to a maximum value in which they stabilize in a level correspondent to the limit distance of spatial dependence, known as range. Measurements located at distances larger than the range have random distribution, the reason why they are independents.

The semivariograms presenting spatial dependency were adjusted with the mathematical model of better correspondence The computational programs and procedures for the construction and adjustment of the semivariogram model followed the instructions of Vieira et al. (2002).

The spatial dependency ratio (GD) was calculated through Equation 2 as the proportion in percentage of the partial sill (C1) in relation to the threshold (C0+C1). According to Zimback (2001), a weak dependency is lower than 25%, a moderate dependency ranges between 26 and 75, and a strong dependence is higher than 75%.

$$GD = \left(\frac{C_1}{C_0 + C_1}\right) \cdot 100 \qquad \text{Eq. 2}$$

Once the semivariogram represents the spatial variability of the data, the geostatistics analysis allowed the comparison of adjustment parameters of the semivariograms for each studied variable.

If the semivariogram shows spatial dependency, through Equation 3 it is possible to estimate values for any other location without data using kriging techniques, which implies trendless estimation conditions and minimum deviations in relation with the known values, that is, with minimum variance (Vieira et al. 2002):

$$\sum_{j=1}^{N} \lambda_j \gamma(X_i, X_j) + \mu = \gamma(X_i, X_0), i = 1, N \sum_{j=1}^{N} \lambda_j = 1 \qquad \text{Eq. 3}$$

where γ(Xi, Xj) is the estimated semivariance using the model adjusted to the semivariogram and correspondent to the distance between the points located in the position (xi, xj) and γ(xi, x_0). Values of weight λ and a multiplier value of Lagrange m, associated to the variance minimization, are generated and with the values λI, values (Z) can be estimated for any location x_0. With the estimated values (Equation 4), isoline maps were built. Thus, hte use of kriging as an interpolator function reveals the spatial variability within the study area.

$$z^{*}(x_0) = \sum_{i=1}^{N} \lambda_i \, Z(x_i) \qquad \text{Eq. 4}$$

3. Results and Discussion

Assimetry and kurtosis close to zero indicate a normal distribution. Low assimetry was observed for silt, clay, and particle density. Low kurtosis was observed for coarse sand, silt, clay, and particle density. High coefficient of variation was observed for all attributes, except for paricle density, indicating variable compatibility of the attributes with the normal distribution (Table 1). Most of the samples have clay or medium texture. Some samples had high silt content, perhaps a consequence of resistant agregates of the clay fraction as the methods used may not have separated the grains of this finer fraction. The particle density had high and positive correlation with the coarse sand fraction (r = 0,94) and negative correlation with the sum of the clay and silt fractions (r = -0,86), at a significance of 0.1%.

Table 1. Statistical parameters for the physical attributes of soils in the Machadinho d'Oeste, Rondônia.

Name	Unit	Mean	Std.Dev.	C.V.	Minimum	Maximum	Skewness	Kurtosis
Coarse sand	g kg^{-1}	270	179	66	40	780	1.020	0.436
Fine sand	g kg^{-1}	167	80	48	60	450	1.397	2.320
Silt	g kg^{-1}	237	121	51	20	630	0.556	0.223
Clay	g kg^{-1}	326	135	41	20	670	0.045	0.078
Real density	g cm^{-3}	2.29	0.15	6	2.08	2.60	0.539	-0.831

Std. Dev. – standart deviation; C.V. – coefficient of variation.

Figure 1 illustrates the spatial variability obtained through geostatistics techniques, semivariogram analyses, kriging interpolation, and isoline mapping.

Among the studied soils, the spheric model had a good adjustment (Table 2), as in the work by Grego & Vieira (2005), who worked with soil physical attributes in a much larger scale and a small distance between the samples. Such work states that the spherical model predominates in soil science. Despite the large distances between the samples, the spatial dependency ratio (GD) was classified as moderate (26-75%) for most of the attributes, except for silt content, which presented strong dependency.

The range varied according to the attributes being lower for coarse sand, silt, and clay, and higher for fine sand and particle density. Figure 1 illustrates semivariograms adjusted by the spherical model for the variable studied.

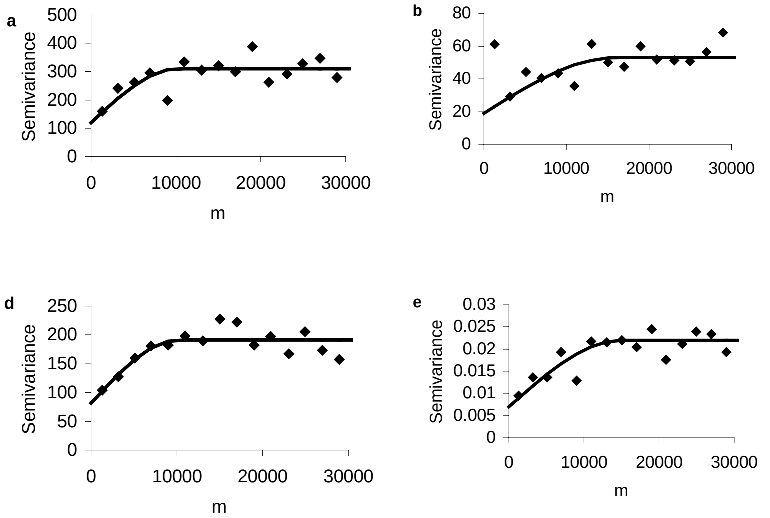

Figure 2. Semivariograms adjusted by the spherical model for coarse sand (a), fine sand (b), silt (c), clay (d) and particle density (e).

Table 2. Spherical model parameters adjusted to the semivariograms: nugget (C_0), sill (C_1+C_0), range (a) and spatial dependency ratio (GD).

Atribute	C_0	C_1+C_0	a (m)	GD (%)
Coarse sand	120.0	310.0	10200	61
Fine sand	19.0	53.0	16000	64
Silt	34.0	148.0	11000	77
Clay	81.6	191.1	10081	57
Particle density	0.007	0.022	15000	26

Visual interpretation of Figure 3 indicates a negative correlation between clay content (3d) with particle density (3e) and with coarse sand (3a). Locations with more clay content have lower particle density and coarse sand content and, consequently, particle density presented positive correlation with coarse sand content. Silt and clay content seems to have no correlation with the other attributes. Soils with medium to high clay content predominate in the study area.

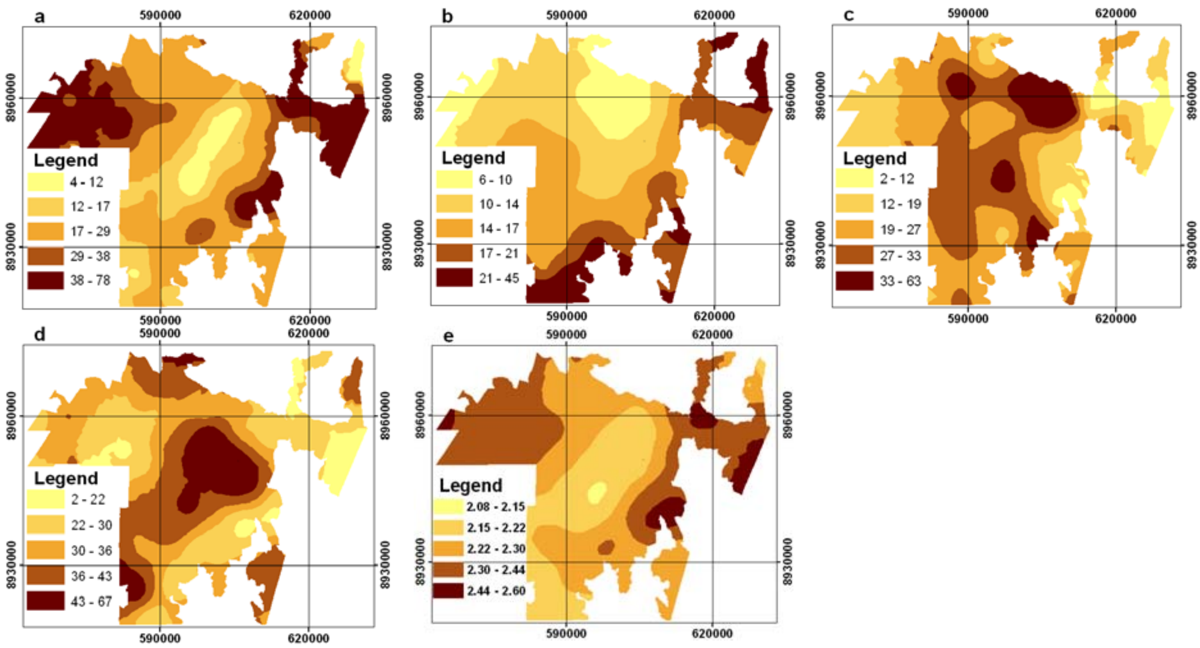

Figure 3. Spatial distribution of coarse sand (a), fine sand (b), silt (c), clay (d), and particle density (e), estimated through kriging techniques.

4. Conclusions

Kriging techniques were suitable to evaluate the spatial distribution of soil attributes despite the large distance between the sampled points. The generated maps can be used to produce derived information, such as environmental risks and as bases for land-use planning. In general, locations with high clay content have lower particle density and coarse sand content. Particle density has positive correlation with coarse sand content and soils with medium to high clay content predominate. The approach based on geostatistics may become a powerful tool to overcome the problem of data gaps, particularly in the Amazon Basin.

Acknowledgments

The authors wish to thank the National Aeronautics and Space Administration (grant #NCC5-695-LBA) and Embrapa Satellite Monitoring for their support.

5. References

Bacci, D.C. 2005. Esboço Geológico da Gleba de Machadinho D Oeste, RO. Campinas: Embrapa Monitoramento por Sa-télite.

Carvalho, M.P.; Takeda, E.Y.; Freddi, O.S. 2003. Variabilidade espacial de atributos de um solo sob videira em Vitório Brasil (SP). Revista Brasileira de Ciência do Solo 27: 695-703.

Cerri, C.E.P.; Bernoux, M.; Chaplot, V.; Volkoff, B.; Victoria, R.L.; Melillo, J.M.; Paustian, K.; Cerri, C.C. 2004. Assessment of soil property spatial variation in na Amazon pasture: basis for selecting na agronomic experimental area. Geoderma 123: 51-68.

EMBRAPA. 1982. Serviço Nacional de Levantamento e Conservação do solo. Levantamento de reconhecimentos de médi-as intensidades dos solos e avaliação da aptidão agrícola das terras em 100.000 hectares da Gleba de Machadinho, no Município de Ariquemes, Rondônia. Rio de Janeiro: Embrapa-SNLCS 16:274.

EMBRAPA. 1997. Centro Nacional de Pesquisa de Solos. Manual de métodos de análises de solos. Rio de Janeiro. 212p.

Facchinelli, A.; Sacchi, E.; Mallen, L. 2001. Multivariate statistical and GIS-based approach to identify heavy metal sources in soils. Environmental Pollution 114: 313-324.

Grego, C.R.; Vieira, S.R. 2003. Variabilidade espacial de propriedades físicas do solo em uma parcela experimental. Revista Brasileira de Ciência do Solo 29: 169-177.

Paz-Gonzáles, A.,Vieira, S.R., Taboada Castro, M.T., 2000. The effect of cultivation on the spatial variability of selected properties of na umbric horizon. Geoderma 97: 273-292.

Trangmar, B. B.; Yost, R. S.; Uehara, G. 1985.Applications of geostatistics to spatial studies of soil properties. Advances in Agronomy 38:45-94.

Valladares, G. S.; Bognola, I. A.; Govêa, J. R. F. 2003. Levantamento de reconhecimento de solos de média intensidade da Gleba Machadinho, RO. Campinas: Embrapa Monitoramento por Satélite.

Valladares, G. S. ;Batistella, M.;Pereira, M. 2005. Comparison between properties of superficial horizons of a Oxisol under different land use/land cover in northeastern Rondônia, Brazilian Amazon.LBA-ECO 9th Science Team Meeting. 45 (Abstr.)

Vendrusculo, L.G. 2001. Desenvolvimento de um sistema computacional para análise geoestatística. M Sc (Thesis) Universidade de Campinas, Campinas.

Vieira, S.R. 2000. Geoestatística em estudos de variabilidade espacial do solo. In: Novais, R.F.; Alvarez V., V.H. & Schaefer, C.E.G.R.(eds) Tópicos em ciência do solo, 1. p.1-53. Sociedade Brasileira de Ciência do Solo. Viçosa.

Vieira, S.R.; Millete, J.; Topp, G.C. & Reynolds, W.D. 2002. Handbook for geostatisticalanalysis of variability in soil and climate data. In: Alvarez, V.; V.H.: Schaefer, C.E.G.R.; Barros, N.F.; Mello, J.W.V. & Costa,L.M., eds. Tópicos em ciência do solo. 2: 1-45. Sociedade Brasileira de Ciência do Solo, Viçosa.

Zimback, C.R.L. Análise especial de atributos químicos de solo para o mapeamento da fertilidade do solo. Botucatu, Unesp, 2001. 114p. Tese de livre docência.

White, J.G., Welch, R.M., Norvell, W.A., 1997. Soil zinc map of the USA using geoestatistics and geographic information systems. Soil Sci. Am. J. 61, 185-194.