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Spatial Variability of Soil Physical and Chemical Attributes Related to Agregation Status of Two Ferralsols Under No-Tillage of the State of São Paulo (Brazil)

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Abstract: The spatial variability of soil physical and chemical attributes presents direct relation with the formation and maintenance of soil aggregates. However, the different soil management systems also interact with these attributes modifying their natural variability. Thus, the objective of this work was to study the spatial variability of the physical and chemical attributes of two Ferralsols of the State of São Paulo, under no-tillage system and its relation with the aggregate stability. The soil samples were collected in the 0 - 10 cm depth, at the nodes of sampling grid of 100 m between points. One of the areas is located near Angatuba, SP, Brazil and the other one in Campos Novos Paulista, SP, Brazil. The physical attributes analyzed were: clay, coarse sand, fine sand and total sand contents and the weighed mean aggregate diameter (MAD) as an indicator of aggregate stability. The soil chemical attributes studied were: organic matter, calcium and magnesium contents. The data were analyzed using descriptive statistics, the analysis of simple linear correlation and by means of geostatistics tools. Once the spatial dependence has been detected by means of the semivariogram, contour maps were constructed using the kriging interpolation technique. The spatial variability for the chemical and physical attributes and their relation to the aggregate stability was influenced by past management history of the areas studied. The Ferralsol in Angatuba presented a similar behavior among maps for the spatial variability for all attributes studied. Continuo's no-tillage for the Ferralsol of Campos Novos Paulista increased the spatial continuity of all studied variables with respect to the Ferralsol of Angatuba. The spacing used in Ferralsol in Campos Novos Paulista was not sufficient to detect the spatial dependence of MAD.

Key words: geostatistics, kriging, variograms, soil physical, soil chemistry, soil management.

INTRODUCTION

The arrangement of the soil solid particles resulting in its structure and aggregation is of vital importance to agriculture, since they are related to the availability of water and air to the roots, with the supply of nutrients, with the mechanical resistance to penetration and the root development. Griffith et al. (1986), describe the state of aggregation as one of the parameters that can be used to measure soil quality. A high index of aggregation indicates good soil structure and a positive influence on plant growth. However, the state of aggregation of soil is subject to change due to natural and man-made phenomena such as the use and management. Different soil attributes influence their state of aggregation, among which: the texture (Feller et al., 1996; Dufranc et al., 2004), the oxides of iron (Fe) and aluminum (Al) (Silva and Kato, 1997), the organic matter content (Feller et al., 1996, and Silva, 1997), microbial activity (Dufranc et al., 2004) and soil management (Dufranc, 2001).

In order for the primary mineral particles to form aggregates, the forces of attraction must exceed the forces of repulsion. According to Brady (1979) and Silva and Kato (1997), organic matter and clays, when combined with appropriate cations, are mainly responsible for the formation of aggregates, acting as cementing agents. However, it must also be considered the influence of soil exchangeable cations in the process of aggregation (Arena, 1968) in a positive manner (Flocculant series) or negative

(Dispersant series). Thus, the state of aggregation of a soil is composed of a complex and closely linked to management, since in that case the soil is managed aiming the optimization of productivity.

Flocculant series :

Al>Fe>H>Ca>Mg>K>NH4>Na>Li : Dispersant series

VIEIRA (2000) emphasizes the importance of incorporating knowledge of the spatial variability of soil attributes for the agricultural production process. In recent years various studies have demonstrated the importance of knowledge of the spatial variability of soil attributes (Cambardella et al., 1994; Vieira, 2000; BERTOLANI and Vieira, 2001, Abreu et al., 2003, Siqueira et al., 2008) .

With respect to the spatial variability of the aggregate stability parameters, Carvalho et al. (2004), which describe the spatial distribution of aggregates is not random, and is the result of different natural processes of formation and maintenance of aggregates which are highly dependent on the system. This study aimed to investigate the spatial variability of physical and chemical attributes of two Ferralsols of the State of São Paulo (Brazil), cultivated with annual crops under no-tillage and its relation to the stability of aggregates.

MATERIAL AND METHODS

One area is located at the Fazenda Planalto, in the municipality of Angatuba, SP, Brazil, whose geographical coordinates are 23° 29' 23'' N and 48º 24’ 46'' W. This experimental area has 90 ha and is irrigated by a center-pivot whose radius reaches 500 m. The soil is classified as a Ferralsol (FAO-ISRIC, 1994) and the climate, according to the classification of Köppen, is type Cfa mesothermic humid, without a well defined dry season, and with the rainfall of 1250 mm year^{-1} (Dufranc, 2001). The area has been managed with crop rotation under no-tillage since 1995, involving soybean (*Glycine max* (L.) Merrill), maize (*Zea mays* L.) and potato (*Solanum tuberosum* L.), the latter introduced in the cropping system every three years with conventional tillage.

The other area is located at the Fazenda Vella Lagoa in the municipality of Campos Novos Paulista (Sao Paulo, Brazil) whose geographical coordinates are 22° 36' 11'' N and 50º 00' 09'' W. The size of the experimental area is about 35 ha, on a slope of 400 m wide by 880 m in length. The soil of the area is a Ferralsol (FAO-ISRIC, 1994) and the climate, according to the classification of Köppen, is type Cfa, tropical humid without dry season, with hot summers, uncommon frost, trend of concentration of rainfall during the summer months and with the annual rainfall of 1200 mm year^{-1} (Dufranc, 2001). The area has been managed since 1995 under the no-tillage system with soybean (*Glycine max* (L.) Merrill) as the summer crop and maize (*Zea mays* L.) as the winter crop and possibly millet (*Pennisetum typhoides* Burm. F.) as the spring crop.

Samples were collected in a uniform square grid with points 100 m apart, totaling 76 sampling points for the area of Angatuba and 37 points for the area of Campos Novos Paulista (Fig. 1).

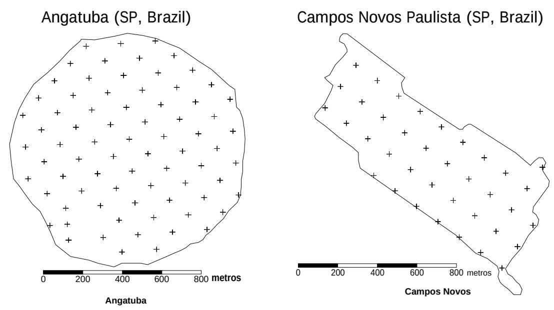

Figure 1. Sampling layout showing sample locations at a 100 m spacing.

Samples were collected after harvest of the summer cropin May 2000, at the depth of 0.0-0.1 m for the analysis of physical and chemical attributes. The physical attributes analyzed were: mean weight diameter of aggregates (MAD), clay, coarse sand, fine sand and total sand. The mean weight diameter of aggregates (MAD) and soil texture were determined according to methodology described by Camargo et al. (1986). The chemical attributes related to aggregate stability analyzed were: organic matter (OM), calcium (Ca) and magnesium (Mg), according to methodology described by Raij et al. (2001).

Data were analyzed using the program STAT (Vieira et al., 2002), which provided the main statistical moments. The set of programs GEOSTAT (Vieira et al., 2002) was used to determine the spatial dependence between samples using the experimental semivariogram (VIEIRA, 2000). Once the spatial dependence between samples are determined, maps of isolines were constructed using the program SURFER 7.0 (Golden Software, 1999).

RESULTS AND DISCUSSION

The statistical parameters of the soil physical and chemical attributes for in Angatuba showed median values of coefficient of variation (CV), except for Ca and Mg data, showing a CV of 28.60 % and 29.86 % respectively, whose values are considered high according to the classification proposed by Gomes and Garcia (2002). This may be related to the management system used in this area, because every three years the land area is cultivated with potato (*Solanum tuberosum* L.) in the conventional system. Thus, the management practice in the potato's crops in the conventional system with application of high fertilizers rates (Reis Junior and Monnerat, 2001), contributed to the occurrence of high values of CV of Ca and Mg, mainly because the soil management changes the natural variability of the attributes (Abreu et al., 2003), due to the for distribuition of fertilizers in the area. The CV for the Campos Novos Paulista are low, and the Mg, Ca, OM, and coarse sand have median values of CV (21.64 %, 18.38 %, 16.91 % and 12.70 %, respectively). Most of the data for the two fields of study did not show normal distribution, with the exception of total sand in Angatuba. The values of skewness and kurtosis for Ca and Mg in Angatuba were also influenced by soil management, as discussed above.

The parameters fitted to the semivariograms are shown in Table 2. Most of the data were fitted to the spherical model, except for Mg and clay content in Angatuba that were fitted to the exponential model and MAD in Campos Novos Paulista which showed pure nugget effect. The occurrence of pure nugget effect for the MAD in Campos Novos Paulista, indicates that the spacing used during the data collection was not sufficient to detect the spatial dependence for this attribute. The choice of the spherical model for most attributes coincides with other studies that describe this model as the one that fits most of the soil and plant parameters (Bertolani and Vieira, 2001). According Cambardella et al. (1994), high values of nugget effect (C_0) represents the variability not detected during sampling. The nugget effect values shown in Table 2 indicate that there is no pattern of occurrence of values of C_0 in both areas of study. However, many attributes have high values of C_0 indicating discontinuity in the spatial variability at small distances. This fact is confirmed by the values of ratio of spatial dependence (SDR) proposed by Cambardella et al. (1994), where the lower the value of SDR represents greater spatial dependence between samples.

Table 1 – Descriptive statistics for the soil physical and chemical attributes related to aggregate stability for the Ferralsol of Angatuba and Campos Novos Paulista (SP, Brazil) .

Attribute	Unit	N	Mean	SD	CV	Minimum	Maximum.	Skewness	Kurtosis
					Angatuba				
OM	g dm^{-3}	75	32.32	3.87	11.97	22.00	40.00	-0.754	0.508
Ca	mmol dm^{-3}	75	35.65	10.19	28.60	18.00	70.00	1.168	2.291
Mg	mmol dm^{-3}	75	16.68	4.981	29.86	10.00	38	2.048	5.526
Clay	g kg^{-1}	75	674.30	28.79	4.27	540.10	721.00	-1.438	5.403
Coarse sand	g kg^{-1}	75	53.37	8.87	16.63	33.60	72.70	-0.134	-0.455
Fine sand	g kg^{-1}	75	125.80	21.23	16.88	81.20	225.80	1.208	5.358
Total sand	g kg^{-1}	75	179.20	26.36	14.71	124.40	294.90	0.943	3.870
MAD	-	75	1.17	0.15	12.91	0.82	1.49	-0.006	-0.678
					Campos Novos Paulista				
MO	g dm^{-3}	37	21.24	3.59	16.91	13.00	32.00	0.619	1.750
Ca	mmol dm^{-3}	37	36.32	6.68	18.38	27.00	56.00	1.163	1.704
Mg	mmol dm^{-3}	37	14.11	3.05	21.64	9.00	25.00	1.310	3.184
Clay	g kg^{-1}	37	178.50	16.14	9.04	149.80	222.50	0.477	0.109
Coarse sand	g kg^{-1}	37	364.40	46.27	12.70	247.50	460.50	-0.079	0.455
Fine sand	g kg^{-1}	37	407.00	33.94	8.34	342.90	477.60	0.055	-0.546
Total sand	g kg^{-1}	37	771.40	20.01	2.60	725.10	817.50	-0.235	0.127
MAD	-	37	0.28	0.01	4.10	0.27	0.33	2.611	9.751

OM: organic matter; Ca: calcium; Mg: magnesium; N: number of samples; SD: standard deviation; CV: coefficient of variation (%); Min.: minimum value; Max.: maximum value.

Table 2 – Semivariogram parameters for the soil physical and chemical attributes related to aggregate stability for the Ferralsol of Angatuba and Campos Novos Paulista (SP, Brazil).

Attribute	Model	C_0	C_1	a	RSD
		Angatuba			
OM	Spherical	0.00	18.71	600.00	0.00
Ca	Spherical	40.00	65.00	200.00	38.09
Mg	Exponential	12.00	17.00	220.00	41.37
Clay	Exponential	275.87	650.00	600.00	29.80
Coarse sand	Spherical	11.65	81.89	600.00	12.46
Fine sand	Spherical	126.41	397.68	600.00	24.12
Total sand	Spherical	46.88	797.08	600.00	5.55
MAD	Spherical	0.02	0.007	500.00	72.45
		Campos Novos Paulista			
MO	Spherical	3.68	9.91	373.37	27.09
Ca	Spherical	27.49	14.24	348.60	65.87
Mg	Spherical	4.57	4.16	392.29	52.33
Clay	Spherical	168.07	100.27	500.00	62.63
Coarse sand	Spherical	31.90	3029.03	500.00	1.04
Fine sand	Spherical	0.00	1504.28	415.45	0.00
Total sand	Spherical	243.98	220.32	500.00	52.55
MAD		Pure nugget effect			

MO: organic matter; Ca: calcium; Mg: magnesium; C_0: nugget effect; C_1: structural variance; a: range; SDR: spatial dependence ratio.

The range (a) for the physical and chemical attributes of Ferralsol in Angatuba reaches values of about 500 m, with the exception of Ca (200 m) and Mg (220 m). The physical and chemical attributes of Ferralsol in Campos Novos Paulista present range values (a) around 350 m. According to Souza et al. (1997) the range values can be used to set the spacing of data collection. However, one should bear in mind that the value range (a) varies between different soil attributes (Vieira, 2000; Bertolani and Vieira, 2001, Siqueira et al., 2008). Therefore, one should also consider the spatial variability of soil attributes is influenced by different management system (Abreu et al., 2003), and with that also have distinct patterns of variability over time (Vieira, 2000). On the other hand, for this study in both areas high values of C0 were found and many of the attributes present medium and low values of SDR which indicate strong spatial dependence between samples. In this case, increasing the spacing between samples could reduce the time and cost spent on the collection and analysis of data, but it does not ensure that the spatial variability can be modeled by the semivariogram with the accuracy needed for the practice of precision agriculture. It is important to remember that for the field in the Campos Novos Paulista regular spacing of 100 m was not sufficient to detect the spatial dependence between samples for MAD.

The maps of isolines for Ferralsol in Angatuba (Fig. 2) confirm that there is a relationship between the physical and chemical attributes related to the stability of aggregates. It was observed that in areas with higher content of OM also show greater MAD, since the interaction between the basic soil particles (clay, silt and sand) and cementing agents (OM and Fe and Al oxides), determines the state of aggregation (Brady, 1979; Silva and Kato, 1997). In this sense, one can see that there is a relationship between the attributes for the two areas with higher clay content for the formation of aggregates. This fact can be explained as the iron oxides (hematite and goethite) and Al (gibsita) are present in clays (Silva and Kato, 1997), hence the higher values of MAD in areas with higher clay content. Dufranc et al. (2004), studying the influence of different aggregating agents in the same area under study concluded that the OM is the main aggregating agent for this area of study.

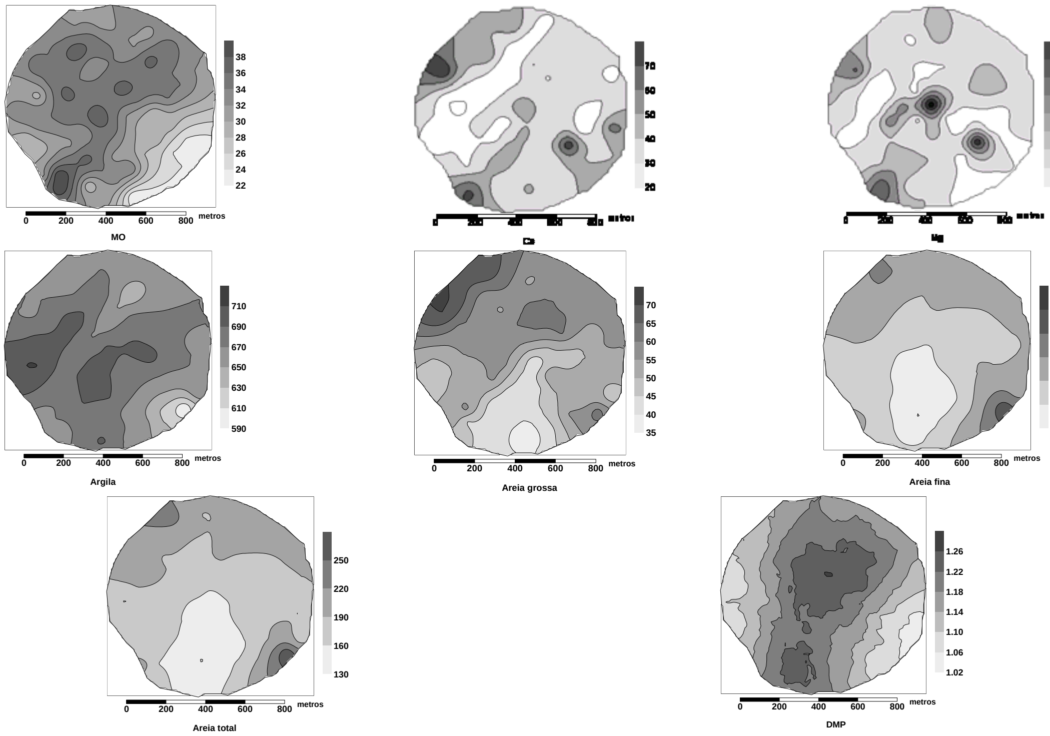

Figure 2 – Spatial variability maps for the soil physical and chemical attributes related aggregates stability for the Ferralsol of Angatuba (SP, Brazil).

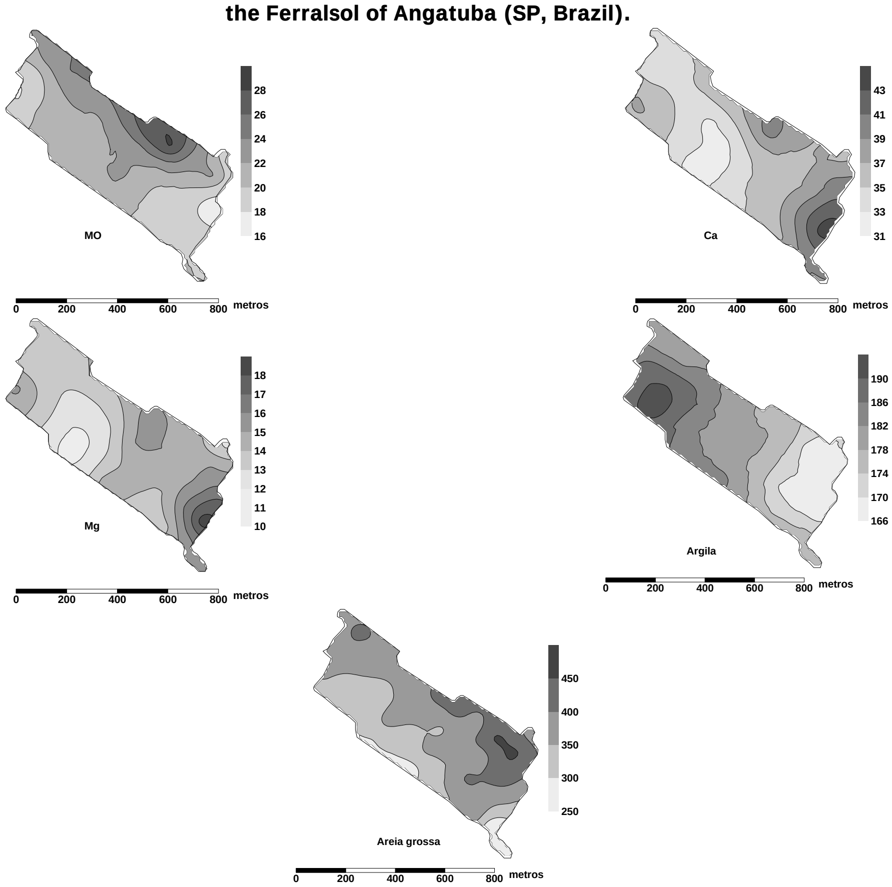

Figure 3 – Spatial variability maps for the soil physical na chemical attributes related aggregates stability for the Ferralsol of Campos Novos Paulista (SP, Brazil).

Regarding the interaction of the maps of Ca and Mg with the MAD, it can be seen on Figure 2 (Angatuba) that the areas with higher concentration of Ca and Mg show lower values of OM and MAD. Westerhof et al. (1999) and Albuquerque et al. (2003), describing the loss of organic matter and the chemical changes resulting from the use of correctives and fertilizers can alter the physical characteristics of the soil. Therefore, the Ca and Mg right after application and in adequate quantities act as aggregating agents (Brady, 1979). However, the excess of these elements in the soil favors the dispersion of clay (Arena, 1968), favoring the decrease of stability of aggregates. Thus, soil management in cultivation with potato (*Solanum tuberosum* L.) every three years in the conventional system may be contributing to the loss of organic matter (Westerhof et al., 1999) and concentration of correctives and fertilizers in some areas (Albuquerque et al., 2003) in Ferralsol in Angatuba. However, even if this fact is occurring the maps of spatial variability of the attributes studied in Angatuba showed a similar pattern of distribution of contour lines.

It should also be considered that in areas with low content of OM, and higher content of Ca and Mg there is also an increase in the levels of sand, mostly fine sand. According to Feller et al. (1996) and Dufranc et al. (2004), areas with high fine snad content have lower values of stability of aggregates. With this, the bottom area shown in the map of the Ferralsol Angatuba occurs in an association between the studied attributes that favors a lower stability of aggregates in this region.

For Ferralsol in Campos Novos Paulista (Fig. 3) it is difficult to relate the physical and chemical attributes with the MAD, as MAD showed pure nugget effect which made it impossible the construction of their map of using geostatistical interpolation. However, it is still possible to make a comparison between the maps of physical and chemical attributes involved in this study. It is noticeable that there is no relationship between the map of spatial variability in OM and clay, because the areas with higher OM are not necessarily the areas with the highest content of clay. The same fact occurs with Ca and Mg.

The other attributes studied in Campos Novos Paulista also did not show any clear relationship between the maps of isolines. Although it is not possible to construct the map of isolines of MAD, it is expected that the spatial behavior for the study area is similar to the spatial behavior of OM and clay, since these two factors are primarily responsible for the state of aggregation in the soil (Brady, 1979; Silva and Kato, 1997). However, Dufranc et al. (2004) studied the importance of different aggregating agents for this same field by multiple linear correlations demonstrated that the most important cementing agents were the bacterial community and the contents of Fe and K. The spatial variability of these parameters previously referred by the author, as they are not part of this study, it is difficult to predict the spatial behavior of the MAD for this field, since the sampling spacing used was not sufficient to detect the spatial variability.

It is possible to also consider that the areas with high fine sand content tend to have low stability of aggregates (Dufranc et al., 2004). This is important because it contributes to the understanding of the relationships between the textural parameters, soil organic matter content and stability of aggregates. Accordingly, it is expected that the higher stability of aggregates in the Ferralsol of Campos Novos Paulista are present in the upper half of the study area, an area which concentrates the apparently higher levels of clay and organic matter.

CONCLUSIONS

The spatial variability of the physical and chemical attributes and its relation with the stability of aggregates was influenced by the history of management of areas under study. The Ferralsol in Angatuba presents a similar behavior between the maps of spatial variability for all attributes studied, even with the presence of greater discontinuity between samples found for most data, as described by high values of nugget effect (C_0).

The spacing used in Ferralsol in Campos Novos Paulista was not sufficient to detect the spatial dependence of MAD, making it difficult to describe their relationship with other physical and chemical attributes involved in this study.

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