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Spatial Distribution of Biological Attributes of Two Ferralsol in The State of São Paulo (Brazil) Under No-Tillage System

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Abstract: In the recent years there have been various reports devoted to the study of spatial variability of soil physical and chemical attributes. However, little is known about the pattern of spatial variability for soil biological attributes. Thus, the objective of this study was to evaluate the spatial distribution of the biological attributes of two Ferralsols in the State of São Paulo (Brazil) under no tillage system, using tools of geostatistics. The samples were collected in fields near the cities of Campos Novos Paulista (37 sampling points) and Angatuba (76 sampling points), at 0 - 10 cm deep in a regular grid of 100 m x 100 m. The biological attributes studied were: microbial biomass carbon (MBC), bacterial population and fungi population. The sampling spacing used in both study areas was not sufficient to detect the spatial dependence for fungi population through the experimental semivariogram, demonstrating that the spatial dependence for this attribute occurs at smaller spacings than the one used in this study. The statistical and geostatistics parameters for biological attributes of Ferralsol in Campos Novos Paulista were more stable, mainly because this area is managed solely under the no tillage with a succession of crops. The microbial biomass carbon (MBC) in Campos Novos Paulista showed high degree of spatial dependence, while the other attributes had median degree. The biological attributes in Angatuba have different spatial variability, when compared with each other, once the scaled semivariogram shows a greater difference mainly between the first pair of semivariance.
Key words: geostatistics, kriging; variograms, soil biology, microbial biomass, soil management.

INTRODUCTION

Most studies on soil spatial variability are mainly dedicated to the physical and chemical attributes (Cambardella et al., 1994, McBratney and Webster, 1986, Vieira et al., 1997; Vieira, 2000, Carvalho et al., 2002, Carvalho et al., 2004), and few studies have evaluated the spatial variability of soil biological attributes

The soil biological attributes, under favorable conditions for their development, have an important role in the state of soil aggregation. Different microorganisms (bacteria, fungi, algae and yeast) are able to unite the soil mineral fraction into stable aggregates, but each organism has a specific performance when it comes to aggregate particles (Harris et al., 1966; Dufranc, 2001; Dufranc et al., 2004). The microbial biomass carbon is related to the soil biological attributes, since it represents the living fraction of soil organic matter formed by microorganisms (Perez et al., 2004). Accordingly, the carbon of microbial biomass is an important component of the assessment of soil quality because it operates in the natural processes of decomposition in the interacting dynamics of nutrient regeneration and the aggregate stability (Franzliebbers et al., 1999, Perez et al. , 2004).

According Mummey et al. (2002), any disturbance in the soil ecosystems affects the normal functioning of the microbial community structure.

Geostatistics, in turn, has been used in recent years as an important tool for modeling and interpretation of spatial variability of different soil attributes (McBratney and Webster, 1986, Cambardella et al., 1994; Vieira, 1997; Vieira, 2000; Mummey et al., 2002). However, the use of geostatistics requires knowledge of simple locations since this knowledge is essential for the understanding of the spatial variation of a particular attribute (Vieira, 2000).

The objective of this study was to analyze the spatial distribution of biological attributes (microbial biomass carbon, population of population of bacteria and fungi) of two Ferralsols of the State of São Paulo (Brazil) cultivated with no tillage, using tools of geostatistics.

MATERIAL AND METHODS

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

The other area is located at a field near Campos Novos Paulista (Sao Paulo, Brazil) whose geographical coordinates are 22 ° 36 '11'' N and 50 º 00' 09'' W. The experimental area is about 35 ha, located on a slope of 400 m wide by 880 m in length. The soil of the area is a Ferralsol (FAO, 1994). The climate, according to the Köppen classification, is type Cfa, tropical humid without dry season, with hot summers, uncommon occurrence of frost, trend of concentration of rainfall during the summer months and with the total rainfall of 1200 mm year^{-1} (DUFRANC, 2001). The area has been cultivated with no-tillage with soybean [*Glycine max* (L.) Merrill] as a 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 for each 100 m apart, totaling 76 sampling points in Angatuba and 37 points in Campos Novos Paulista (Fig. 1).

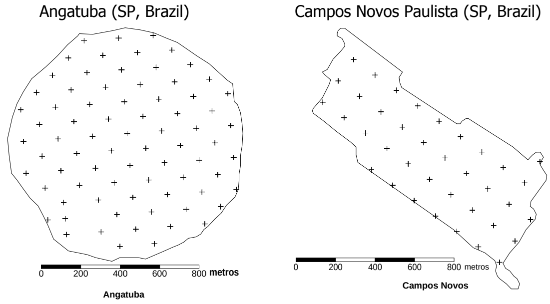

Figure 1. Sampling layout showing 100 m spacing square grid.

The sample collection was performed after harvest of the crop of summer in May 2000, at a depth of 0.0-0.1 m for analysis of the following biological soil attributes: microbial biomass carbon (MBC), population of population of bacteria and fungi. The microbial biomass carbon (μgC g^{-1}) is measured by the fumigation-extraction method (Vance et al., 1987), based on the fact that the carbon of the microorganisms killed by fumigation is released to the soil, where it can be extracted chemically. Fumigated and unfumigated subsamples are subjected to extraction with K_2SO_4 (0.5 mol L^{-1}) for 2 h under stirring, and then are centrifuged and filtered. The supernatant $K_2Cr_2O_7$ and H_2SO_4 receive the oxidized carbon. The excess of dichromate is titrated with Fe (NH_4) (SO_4), from which one can calculate the amount of carbon extracted from the sample.

The quantification of microorganisms is done by the method of dilution plating. Ten grams of soil is suspended in 90 mL of sterile solution of 0.01 mol L^{-1} $MgSO_47H_2O$ and agitated for about 10 minutes. From this suspension, the dilution factor 10 is prepared, in studies testing the same solution. Aliquots of 0.1 mL of the dilutions are spread in Petri dishes with the culture medium suitable for the organism you wish to count. For fungi the Martin media is used, and actinomycetes + bacteria, extract from soil media. The plates are placed in an incubator at 28 º C, and when a visually growth is detected, colonies of each microbial group are counted. The result is given as colony-forming units (ufcs).

The main statistical moments: mean, standard deviation (SD), coefficient of variation (CV, %), minimum (Min), maximum (Max), coefficient of skewness (Skew.) and coefficient of kurtosis (Kurt.) were determined using the program STAT (Vieira et al., 2002). Linear correlations were performed between all combinations of pairs of soil biological variables, to verify possible relationships between the attributes analyzed.

The analysis of spatial variability was performed using the set of programs GEOSTAT (Vieira et al., 2002), where the spatial dependence between samples is modeled by the experimental semivariogram (Vieira, 2000). The scaling of the semivariogram (Vieira et al., 1997) was used for the purpose of grouping the semivariograms of individual attributes studied in the same graph.

The program SURFER 7.0 (Golden Software, 1999) was used for construction of maps of isolines for the attributes that showed spatial dependence.

RESULTS AND DISCUSSION

It appears that all attributes have high coefficients of variation (CV, Table 1), except for microbial biomass carbon (MBC), which presents a low CV, according to the classification of Gomes and Garcia (2002). The analysis of a minimum, maximum and average values, indicates distance all attributes have a large variation. This fact is confirmed by the analysis of coefficients of skewness and kurtosis that describe a non-normal distribution of frequency for the attributes studied. According to Carvalho et al. (2004), an attribute with a normal distribution should have skewness and kurtosis values, near 0 and 3.

Coleman and Hendrix (2000) describe that in terms of cultivation, the balance of microorganisms in the soil is disturbed and some have a population increase with great intensity to a much higher development of all groups. Thus, we can say that the great variability of statistical parameters for the attributes examined is mainly because the microbial activity is related to the amount of inorganic nutrients, water availability, temperature, aeration and pH (Harris et al., 1966).

Data analysis by means of simple linear correlation (Table 2) showed no consistent results, where the highest correlation coefficient was 0.329 MBC and the fungi population in Ferralsol in Angatuba.

With respect to the semivariogram parameters (Table 3) it can be seen that the population of fungi showed pure nugget effect in both areas of study. The occurrence of pure nugget effect means that the spacing used was not sufficient to detect the spatial variability of the population of fungi. The values of nugget effect (C_0) indicate that the small distance spatial discontinuity between the biological attributes analyzed for the two areas is described in the following order: MBC <population of bacteria <population of fungi.

The values of range (a) show different behavior in each area of study. The MBC and the population of bacteria in Angatuba presented range values from 600.00 m and 363.91 m, respectively. For Campos Novos Paulista the population of bacteria and MBC showed range values from 211.84 m and 314.50 m, respectively. It is known that the soil management alone operates substantially on the size and activity of microbial population (Barrot and Nahas, 2000). Therefore, the presence of different values for range (a) for the biological attributes in Campos Novos Paulista and Angatuba are affected by differences in soil management. This fact is confirmed, since the Ferralsol in Angatuba is cultivated with potato (*Solanum tuberosum* L.) every three years under the conventional system, which contributes to reducing the soil biological attributes, because the soil tillage acuses greater oxidation of organic matter (Mendez et al., 2003).

The values of ratio of spatial dependence (RD) were calculated according Cambardella et al. (1994) (0.0 - 25.00 high, 25.00 to 75.00 and average 75.00 to 100.00 low spatial dependence between samples). The highest spatial dependence between samples occurs in Ferralsol in Campos Novos Paulista for microbial biomass carbon (MBC, 16.72 %). The other attributes have median spatial dependence ratio (SDR).

The spherical model fit to all experimental semivariograms, confirming this as the mathematical model that best suits most of soil and plant parameters (McBratney and Webster, 1986, Carvalho et al., 2002).

The fact that MBC presented better fit parameters for the semivariograms, is explained considering that this attribute involves not only the population of fungi and bacteria, but because it encompasses and includes all living fraction of soil organic matter that is composed of bacteria, fungi, actnomicetos, protozoa and algae (Perez et al., 2004).

Table 1. Statistical parameters for soil biological attributes in the two study areas.

Attributes	Unit	N	Mean	SD	CV (%)	Min.	Max.	Skew.	Kurt.
					Angatuba				
MBC	$\mu gC\ g^{-1}$	75	543.40	236.70	43.57	154.80	1174.00	0.341	-0.624
Fungi population	ufcs	73	79370	59070	74.43	19000	435000	3.586	18.490
Bacteria population	ufcs	73	11710000	$6.3E^{+06}$	54.03	$9.0E^{+05}$	$3.4E^{+07}$	0.854	1.302
					Campos Novos Paulista				
MBC	$\mu gC\ g^{-1}$	37	661.10	100.90	15.26	436.90	867,90	-0.291	-0.031
Fungi population	ufcs	37	187700	181800	96.84	51400	997.800	3.410	12.570
Bacteria population	ufcs	37	$2.0E^{+07}$	$1.0E^{+07}$	81.82	$3.E^{+06}$	$5.E^{+07}$	1.431	1.937

N: number of samples; SD: standard deviation; CV: coefficient of variation; Min.: minimum value; Max.: maximum value; Skew.: skewness; Kurt.: kurtosis.

Table 2. Correlation between soil biological attributes for the two study areas.

	Angatuba		
	MBC	Fungi population	Bacteria population
MBC	1.000	-	-
Fungi population	0.329	1.000	-
Bacteria population	-0.137	0.132	1.000
	Campos Novos Paulista		
	MBC	Fungi population	Bacteria population
MBC	1.000	-	-
Fungi population	-0.290	1.000	-
Bacteria population	-0.289	0.023	1.000

Table 3. Semivariogram parameters for the soil biological attributes for the two study areas.

Attributes	Model	C_0	C_1	a (m)	r^2	SDR (%)
			Angatuba			
MBC	Spherical	19840.87	44494.89	600.00	0.8109	30.84
Fungi population			Pure nugget effect			
Bacteria population	Spherical	$2.8E^{+13}$	$1,60E^{+13}$	363.91	0.7128	63.64
			Campos Novos Paulista			
MBC	Spherical	1687.60	8407.89	211.84	0.5208	16.72
Fungi population			Pure nugget effect			
Bacteria population	Spherical	$1.0E^{+14}$	$7.3E^{+13}$	314.50	0.1936	57.80

C_0: nugget effect; C_1: structural variance; a: range (m); r^2: coefficient of correlation; SDR: spatial dependence ratio.

The scaled semivariogram (Fig. 2) for the two areas of study indicates that the population of fungi does not have any relation with other attributes involved in this study. For other attributes there is some relationship between pairs of semivariance, since the data followed a pattern of increasing similarity until they stabilize.

The scaled semivariogram of biological attributes of soil in Campos Novos Paulista shows that there is a pattern in the spatial distribution between pairs of semivariance of MBC and the population of bacteria. The biological attributes in Angatuba did not show similarity in the distribution of pairs of semivariance.

The contour of maps (Fig. 3) of the biological attributes of the Ferralsol in Angatuba show that there is a reversal in the spatial pattern, where the areas with the highest values of microbial biomass carbon (MBC) show the lowest values of the population of bacteria. At first this fact could be explained by soil management in the study area which involves direct sowing soybean (*Glycine max* (L.) Merril) and maize (*Zea mays* L.) and conventional tillage for potato (*Solanum tuberosum* L.) every three years. Pereira et al. (2000), studying the dynamics of the population of bacteria in a soil with the same characteristics of the study area and under different management systems, found that growing soybeans with conventional systems in this soil resulted in the imbalance of populations of bacteria to 30 (1230.3 ufcs), 90 (467.7 ufcs) and 180 days (776.2 ufcs) after fertilization. It was observed that for the area in Angatuba the average population of bacteria (Table 1, 11710000.00 ufcs) is much higher than the values found by the author previously described. However, the reversal of homogeneous regions for the spatial variability Ferralsol in Angatuba, may be associated with changes in vegetation cover and soil pH, the effects of which affect the composition of the microbial population in soil (Barrot and Nahas, 2000, Mendes et al., 2003).

The soil biological attributes in Campos Novos Paulista (Fig. 3) also describe a reversal of the values of microbial biomass carbon (MBC) and the population of bacteria. However, this area is managed solely by no-tillage and crop rotation (soybean, maize and millet) and it can be seen that the values of the population of bacteria are much greater in this area than in Ferralsol in Angatuba. This fact can be explained considering that in this area there is no mobilization of the soil at any time, which favors an increase in the levels of soil organic matter and stable in time through the maintenance of the straw on the surface, with consequent concentration of fertilizers and correctives on the soil surface (Anghinoni and Amaral, 2001), when compared to Ferralsol in Angatuba.

With respect to microbial biomass data Perez et al. (2004) describe that in the no-tillage system this attribute is much more stable than in other management systems, confirming the differences between the Ferralsol of Angatuba and Campos Novos Paulista. Thus, one can explain the presence of a few areas with low concentration of MBC in Ferralsol in Campos Novos Paulista compared to Ferralsol in Angatuba (Fig. 3). Thus, in Ferralsol in Campos Novos Paulista it seems to occur a certain homogeneity in the spatial distribution of the contour lines of the MBC, and result in greater stability of microbiological agents in that area. Thus, the greatest differences between the contour maps for the two areas of study may be related mainly to the maintenance of supplies and straw on the surface due to the no-tillage system. Moreover, the fact that the Ferralsol in Angatuba is cultivated with potato (*Solanum tuberosum* L.) in the conventional system every three years, favors the mineralization of organic matter (Mendez et al., 2003, Perez et al., 2004), with consequent imbalance in the population of microorganisms in the soil (Mendes et al., 2003), explaining the presence of biological values of attributes always lower when compared to the Ferralsol in Campos Novos Paulista.

CONCLUSIONS

The sample spacing used in both areas of study was not sufficient to detect the spatial dependence of the population of fungi by means of the experimental semivariogram, indicating that for this attribute the spatial dependence occurs at lower densities than the one use in the study used. The statistical and the geostatistical parameters for the Ferralsol in Campos Novos Paulista were more stable, mainly because this area is managed solely in no-tillage system with a succession of crops.

The microbial biomass carbon (MBC) in Campos Novos Paulista showed high ratio of spatial dependence, while the other attributes showed median ratio of spatial dependence. The biological attributes in Angatuba have different spatial variability when compared with each other, since the scaled semivariogram shows a greater difference mainly between the first pair of semivariance.

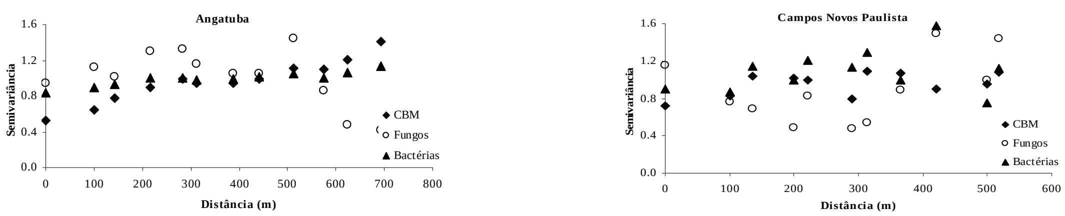

Figure 2. Scaled semivariograms for soil biological attributes of the two study areas.

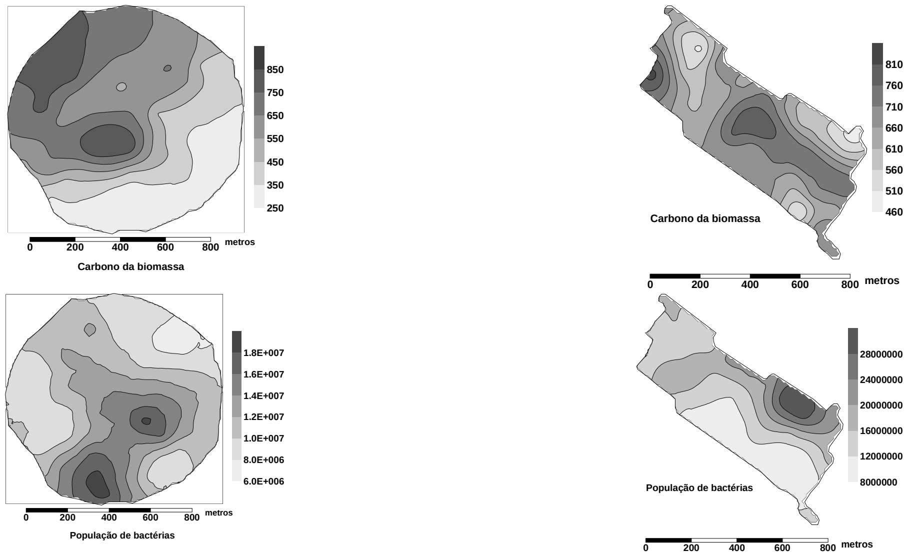

Figure 3. Contour maps for the soil biological attributes that presented spatial dependence for the two areas under study.

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