# GEOSTATISTICAL ANALYSIS FOR SOIL MOISTURE CONTENT UNDER THE NO TILLAGE CROPPING SYSTEM

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ABSTRACT: Experiments in agriculture usually consider the topsoil properties to be uniform in space and, for this reason, often make inadequate use of the results. The objective of this study was to assess the variability for soil moisture content using geostatistical techniques. The experiment was carried out on a Rhodic Ferralsol (typic Haplorthox) in Campinas, SP, Brazil, in an area of 3.42 ha cultivated under the no tillage system, and the sampling was made in a grid of 102 points spaced 10 m × 20 m. Access tubes were inserted down to one meter at each evaluation point in order to measure soil moisture contents ($cm^3\ cm^{-3}$) at depths of 30, 60 and 90 cm with a neutron moisture gauge. Samplings were made between the months of August and September of 2003 and in January 2004. The soil moisture content for each sampling date was analyzed using classical statistics in order to appropriately describe the central tendency and dispersion on the data and then using geostatistics to describe the spatial variability. The comparison between the spatial variability for different samplings was made examining scaled semivariograms. Water content was mapped using interpolated values with punctual kriging. The semivariograms showed that, at the 60 cm depth, soil water content had moderate spatial dependence with ranges between 90 and 110 m. However, no spatial dependence was found for 30 and 90 cm depths in 2003. Sampling density was insufficient for an adequate characterization of the spatial variability of soil moisture contents at the 30 and 90 cm depths.
Key words: neutron moisture gauge, semivariogram, spatial and temporal variability

# ANÁLISE GEOESTATÍSTICA DO TEOR DE ÁGUA DO SOLO SOB SISTEMA DE CULTIVO EM PLANTIO DIRETO

RESUMO: Experimentos em agricultura geralmente consideram as propriedades do solo como sendo uniformes no espaço e, por esta razão, os resultados são freqüentemente mal interpretados. O objetivo deste estudo foi avaliar a variabilidade do teor de água do solo usando técnicas de geoestatística. O experimento foi desenvolvido em um Latossolo Vermelho eutroférrico, Campinas, SP, Brasil, numa área de 3,42 ha sob plantio direto, e a amostragem foi realizada em 102 pontos dispostos em uma grade de 10 × 20 metros. Tubos de acesso foram inseridos até um metro de profundidade em cada ponto para medir o teor de água do solo ($cm^3\ cm^{-3}$) a 30, 60 e 90 cm de profundidade com uma sonda de nêutrons. As amostragens foram realizadas em agosto e setembro de 2003, e em janeiro de 2004. Os dados foram analisados usando estatística clássica para descrever adequadamente a tendência central e a dispersão dos dados e a variabilidade espacial foi analisada usando a geoestatística. A comparação entre a variabilidade espacial para diferentes amostragens foi verificada através da análise de semivariogramas escalonados. O teor de água do solo foi mapeado usando a interpolação de dados com krigagem pontual. Os semivariogramas mostraram moderada dependência espacial para todas as épocas de amostragens a 60 cm de profundidade, com alcance de 90 a 110 m. Entretanto, para 30 e 90 cm de profundidade não foi detectada em 2003 dependência espacial. A densidade de amostragem foi insuficiente para expressar a variabilidade espacial a 30 e 90 cm de profundidade.
Palavras-chave: sonda de nêutrons, semivariograma, variabilidade espacial e temporal

## INTRODUCTION

Soil water content varies in space as a consequence of the variability of other related properties and its study is necessary to know how this variation occurs in space and time. Soil conservation management systems such as no tillage offer protection against erosion, increasing water absorption and infiltration (Derpsch et al., 1991, Grego & Benez, 1999). According to Martinho (2000), owing to the soil physical changes implied to the soil surface layer in the no tillage system, it is necessary to study the spatial variability in order to adequately characterize the environment. The spatial variability can be analyzed using geostatistics that involves a sequence of procedures for the construction of contour maps (Campbell, 1978; Burgess & Webster, 1980; Vieira et al., 1981; 1983; Vauclin et al., 1983; Vauchaud et al., 1985; Wendroth et al., 1997; Vieira, 2000; Grego & Vieira, 2005).

Adequate information about soil properties showing spatial distribution stable in time could contribute to significantly reduce the number of measurements (Vauchaud et al., 1985; Kachanoski & De Jong 1988). Soil moisture content analyzed in consecutive sampling dates have been reported having temporal stability (Vauchaud et al., 1985; Gonçalves et al., 1999). Vauchaud et al. (1985) addressed the occurrence of temporal stability of the spatial distribution of soil moisture content and concluded that the places where higher water content occur in one moment may remain that way at other moments. Vieira et al. (1991) expanded this concept and considered the scaling of semivariograms to simultaneously examine the spatial variability in consecutive sampling dates.

The objective of this study was to assess the variability of soil moisture contents sampled at different dates under the no tillage cultivation system using geostatistical techniques in a Rhodic Ferralsol.

## MATERIAL AND METHODS

### Experimental area

The experiment was carried in Campinas, São Paulo, Brazil, 22°53' South and 47°04' West, at a mean elevation of 600 m above sea level and 6.5% slope, in an area of 3.42 ha, from August 2003 to January 2004. The soil was classified as Rhodic Ferralsol, typic Haplorthox (Oliveira et al., 1989). The study area was divided in a rectangular grid with 10 m spacing for direction X and 20 m for Y resulting 102 sampling points (Figure 1).

### Data sets

Access tubes were inserted down to 1 m at each sampling point to receive a neutron moisture probe, as described in Gomide (2001), for measurements at three layers 15-45 cm, 45-75 cm and 75-105 cm, here represented as 30, 60 and 90 cm depths. Measurements were taken on seven occasions between the end of the winter and beginning of the spring of 2003 and four occasions in January 2004. During the first seven samplings the field was vegetated with grain sorghum and the other four samplings with soybean, both cultivated using the no tillage system.

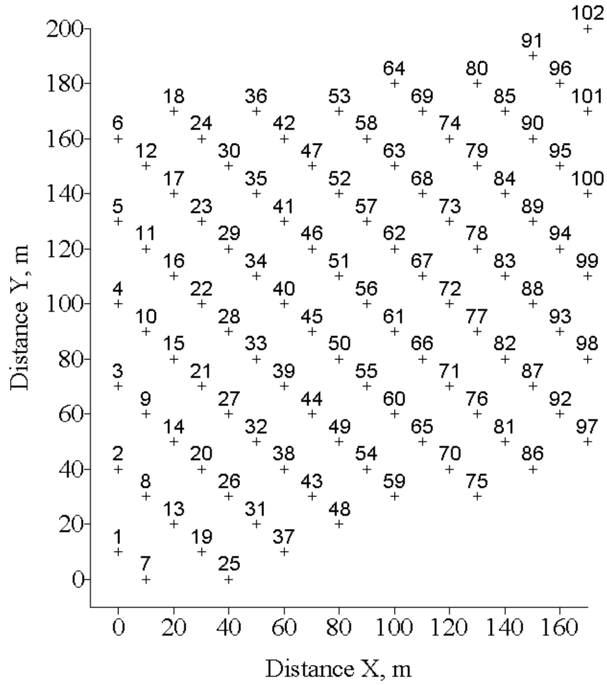



Figure1 - Sampling Grid with 102 points (10 × 20 m).

The neutron count ratio CR was transformed into volumetric soil moisture content θ ($cm^3cm^{-3}$) data according to a previously obtained calibration:

$$CR = \frac{Reading}{CP} \quad (1)$$

and

$$\theta = 0.357CR - 0.0845 \quad (2)$$

where CP is the standard count.

### Data analysis

Initially the statistical parameters (mean, variance, coefficient of variation, minimum value, maximum value, skewness, kurtosis) were obtained in order to verify existence of a central tendency and dispersion of the data using the Stat program (Vieira et al., 1983). When a data set approaches the normal distribution, the values for skewness and kurtosis coefficients approach zero. These values together with the other classical statistical parameters are useful to evaluate the magnitude of the data dispersion around a central tendency value.

The spatial variability was analyzed using semivariograms obtained with program Avario described in Vieira et al. (1983) obtaining the parameters of the models fitted to individual semivariograms (Vieira, 2000). Scaled semivariograms were calculated according to Vieira et al. (1997) in order to plot them with the semivariances on the same scale. The semivariogram, $\gamma(h)$, of n spatial observations $z(x_i)$, i=1, n, can be calculated using Equation [3].

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad (3)$$

where N(h) is the number of pairs of observations separated by a distance h.

Spherical mathematical models were adjusted to the experimental semivariograms, which allowed the visualization of the nature of the spatial variation of the variable. The criteria and program for calculation and fitting a model to the semivariogram are described in Vieira et al. (1983) through which the following parameters were determined: nugget $C_0$, sill $(C_0+C_1)$, and range of spatial dependence a. The degree of spatial dependence (GD) was calculated using Equation [4].

$$GD = \left(\frac{C_0}{C_0 + C_1}\right) * 100 \quad (4)$$

According to Cambardella et al. (1994), the GD represent the spatial randomness and can be used to classify the spatial dependence as strong if GD < 25%, moderate for GD between 26% and 75% and weak with GD > 75%.

Soil moisture contents that showed that the semivariance depended on distance were interpolated, without bias and with minimum variance using the kriging system (Vieira, 2000). The kriging estimator $z^*(x_0)$ at location $x_0$ is expressed by:

$$z^*(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \quad (5)$$

where $\lambda_i$ is the kriging weight associated with observation i at location $x_i$. When submitted to unbiasedness and minimum variance conditions, the kriging system, in terms of semivariogram, becomes:

$$\sum_{j=1}^{n} \lambda_j \gamma(x_i, x_j) + \mu = \gamma(x_i, x_0) \qquad i = 1,2,\ldots,n \quad (6)$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

where $\mu$ is the Lagrange multiplier.

Kriging was used in this study to provide values at every meter spacing both in the X and Y directions in order to properly build contour maps of soil moisture contents for different sampling dates with Surfer program (Golden Software, 1999).

## RESULTS AND DISCUSSION

The statistical parameters of all the analyzed variables are given in Table 1. According to the classification suggested by Warrick & Nielsen (1980), the coefficients of variation were low when the soil had higher water contents. For most of the samplings soil moisture content was normally distributed as indicated by the close to zero coefficients of skewness and kurtosis.

Mean values of soil moisture content at the depths of 30, 60 and 90 cm presented small variation in 2003. On the other hand, for 2004 the mean soil moisture values had increased up to 0.335 $cm^3\ cm^{-3}$ in 1/8/04 at the 30 cm depth and 0.335 $cm^3\ cm^{-3}$ in 1/29/04 at the 60 cm depth. This is explained by the increase in precipitation in this period (Figure 2). On the other hand, the coefficients of variation, although low as usual (Vieira et al., 2003), were more constant for 2003, except in 8/20/03 at the 30 cm depth.

The parameters fitted to the semivariograms and corresponding GD are shown in Table 2.

The soil moisture contents measured at 30 cm and 90 cm in 2003 had pure nugget effects for all dates and in 2004 had weak spatial dependence as shown by the parameter GD (Table 2 and Figure 3). On the other hand, for 60 cm, for both years a moderate GD was found. It seems clear that the 102 points sampled were not close enough together to characterize the spatial variability at 30 and 90 cm. The rea-

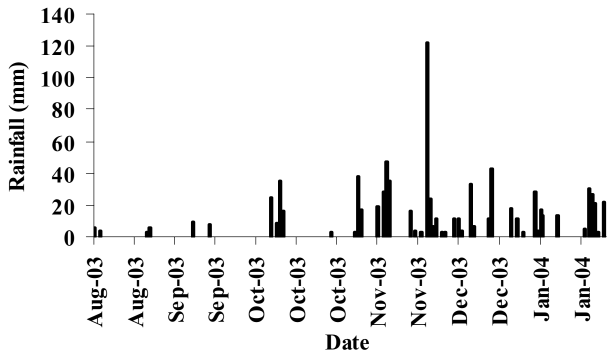



Figure 2 - Rainfall (mm) from August 2003 to January 2004, Experimental Center of Campinas, IAC, Campinas, SP.

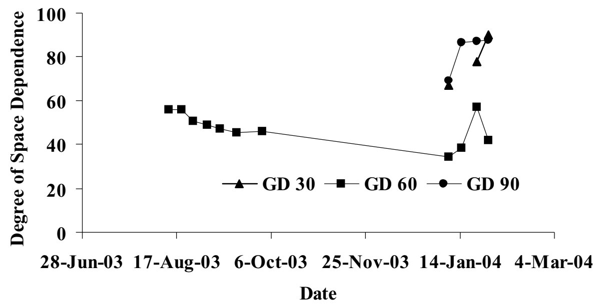



Figure 3 - Degree of space dependence according to sampling date.

Table 1 - Statistical parameters of soil moisture content ($cm^3 cm^{-3}$) during 2003 and 2004.

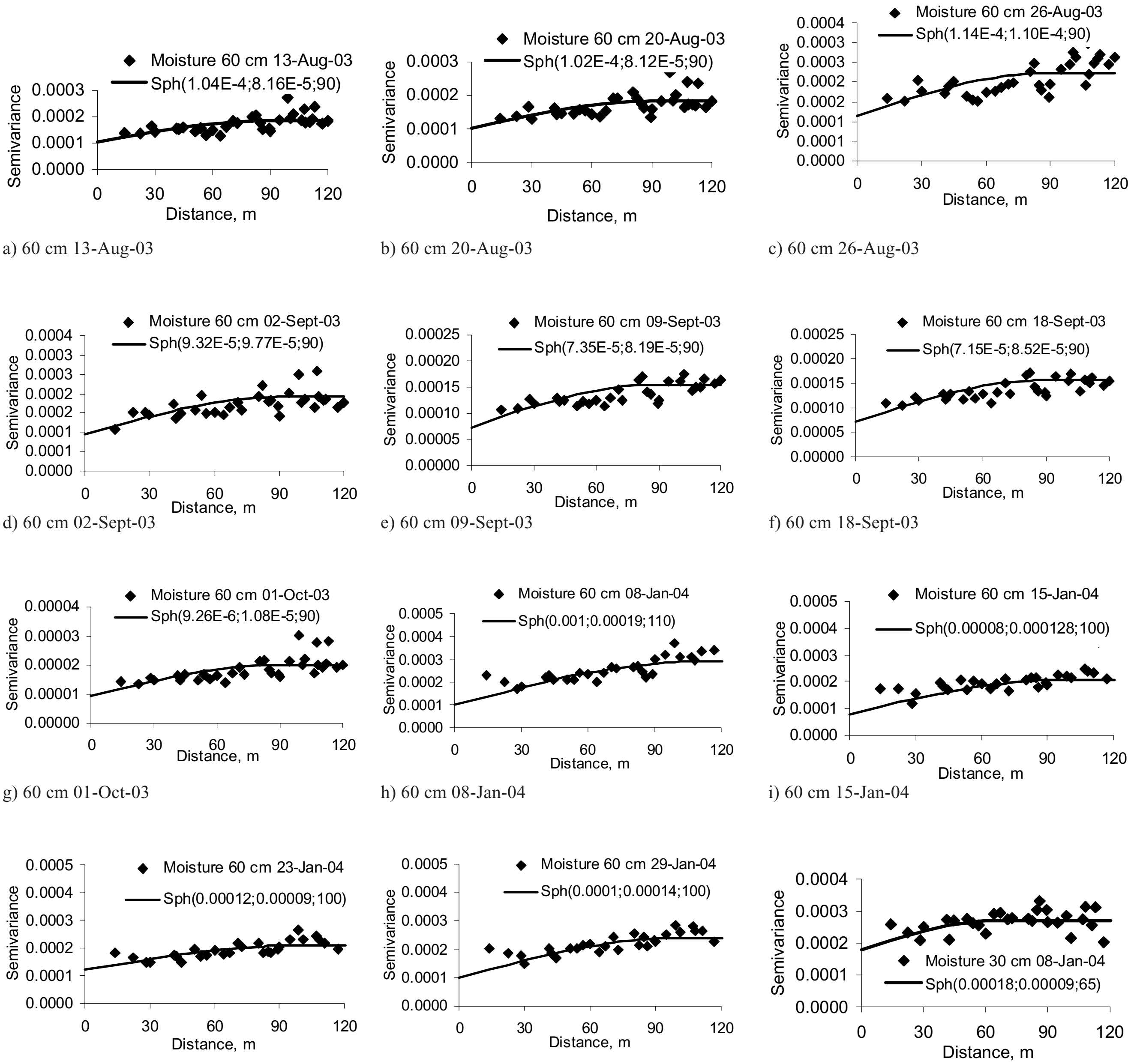
| Date | Mean | Variance | Coefficient of Variation | Minimum Value | Maximum Value | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| | $cm^3 cm^{-3}$ | | % | ------------- $cm^3 cm^{-3}$ | ------------- | | |
| 30 cm depth | | | | | | | |
| Aug13 | 0.279 | 0.00021 | 5.14 | 0.219 | 0.325 | -0.02 | 3.11 |
| Aug20 | 0.295 | 0.00074 | 9.21 | 0.220 | 0.359 | 0.04 | -0.05 |
| Aug26 | 0.269 | 0.00016 | 4.68 | 0.240 | 0.308 | 0.59 | 0.99 |
| Sep02 | 0.264 | 0.00015 | 4.67 | 0.237 | 0.300 | 0.26 | 0.38 |
| Sep09 | 0.259 | 0.00016 | 4.85 | 0.226 | 0.289 | -0.04 | 0.30 |
| Sep18 | 0.267 | 0.00013 | 4.29 | 0.235 | 0.303 | 0.08 | 1.05 |
| Oct01 | 0.259 | 0.00016 | 4.90 | 0.222 | 0.290 | -0.24 | 0.64 |
| Jan08 | 0.335 | 0.00026 | 4.84 | 0.286 | 0.371 | -0.81 | 1.18 |
| Jan15 | 0.325 | 0.00034 | 5.67 | 0.238 | 0.367 | -1.75 | 5.44 |
| Jan23 | 0.301 | 0.00022 | 4.97 | 0.259 | 0.348 | -0.10 | 0.96 |
| Jan29 | 0.335 | 0.00025 | 4.71 | 0.282 | 0.380 | -0.94 | 2.37 |
| 60 cm depth | | | | | | | |
| Aug13 | 0.282 | 0.00018 | 4.77 | 0.253 | 0.330 | 0.32 | 0.86 |
| Aug20 | 0.281 | 0.00017 | 4.70 | 0.254 | 0.322 | 0.13 | -0.05 |
| Aug26 | 0.284 | 0.00022 | 5.26 | 0.228 | 0.324 | -0.17 | 1.37 |
| Sep02 | 0.282 | 0.00019 | 4.83 | 0.242 | 0.312 | -0.17 | 0.10 |
| Sep09 | 0.279 | 0.00015 | 4.43 | 0.251 | 0.316 | 0.39 | 0.40 |
| Sep18 | 0.279 | 0.00015 | 4.39 | 0.254 | 0.313 | 0.20 | -0.15 |
| Oct01 | 0.277 | 0.00014 | 4.32 | 0.255 | 0.309 | 0.28 | -0.48 |
| Jan08 | 0.308 | 0.00029 | 5.52 | 0.270 | 0.371 | 0.27 | 0.96 |
| Jan15 | 0.315 | 0.00022 | 4.67 | 0.280 | 0.364 | -0.02 | 0.63 |
| Jan23 | 0.304 | 0.00022 | 4.91 | 0.268 | 0.347 | -0.03 | 0.32 |
| Jan29 | 0.333 | 0.00025 | 4.78 | 0.292 | 0.380 | -0.06 | 0.54 |
| 90 cm depth | | | | | | | |
| Aug13 | 0.286 | 0.00017 | 4.52 | 0.248 | 0.324 | 0.09 | 0.54 |
| Aug20 | 0.284 | 0.00019 | 4.88 | 0.251 | 0.315 | 0.02 | -0.40 |
| Aug26 | 0.288 | 0.00018 | 4.66 | 0.256 | 0.317 | 0.09 | -0.46 |
| Sep02 | 0.284 | 0.00017 | 4.57 | 0.251 | 0.317 | 0.05 | -0.17 |
| Sep09 | 0.282 | 0.00016 | 4.49 | 0.254 | 0.317 | 0.23 | -0.03 |
| Sep18 | 0.282 | 0.00015 | 4.41 | 0.251 | 0.313 | 0.01 | -0.35 |
| Oct01 | 0.279 | 0.00016 | 4.51 | 0.246 | 0.313 | 0.10 | -0.08 |
| Jan08 | 0.302 | 0.00014 | 3.97 | 0.262 | 0.341 | 0.26 | 2.00 |
| Jan15 | 0.313 | 0.00012 | 3.47 | 0.283 | 0.350 | -0.07 | 1.70 |
| Jan23 | 0.303 | 0.00016 | 4.17 | 0.267 | 0.348 | 0.54 | 2.59 |
| Jan29 | 0.335 | 0.00012 | 3.27 | 0.302 | 0.364 | 0.02 | 0.75 |

Table 2 - Parameters of semivariograms, nugget $C_0$, sill $C_1$, range of spatial dependence A (m), coefficient variation $r^2$ and the degree of space dependence GD (%).

| Date | Co | $C_1$ | A | $r^2$ | GD |
|---|---|---|---|---|---|
| | | | 30 cm depth | | |
| Aug13 | | | PURE NUGGET EFFECT | | |
| Aug20 | | | PURE NUGGET EFFECT | | |
| Aug26 | | | PURE NUGGET EFFECT | | |
| Sep02 | | | PURE NUGGET EFFECT | | |
| Sep09 | | | PURE NUGGET EFFECT | | |
| Sep18 | | | PURE NUGGET EFFECT | | |
| Oct01 | | | PURE NUGGET EFFECT | | |
| Jan08 | 0.000180 | 0.000900 | 65 | 0.411 | 66.67 |
| Jan15 | | | PURE NUGGET EFFECT | | |
| Jan23 | 0.000160 | 0.000045 | 40 | 0.319 | 78.04 |
| Jan29 | 0.000220 | 0.000022 | 25 | 0.146 | 90.00 |
| | | | 60 cm depth | | |
| Aug13 | 0.000104 | 0.000082 | 90 | 0.288 | 55.97 |
| Aug20 | 0.000102 | 0.000081 | 90 | 0.283 | 55.60 |
| Aug26 | 0.000114 | 0.000110 | 90 | 0.312 | 50.83 |
| Sep02 | 0.000093 | 0.000098 | 90 | 0.273 | 48.83 |
| Sep09 | 0.000074 | 0.000082 | 90 | 0.348 | 47.30 |
| Sep18 | 0.000071 | 0.000085 | 90 | 0.323 | 45.60 |
| Oct01 | 0.000009 | 0.000011 | 90 | 0.322 | 46.16 |
| Jan08 | 0.000100 | 0.000190 | 110 | 0.472 | 34.48 |
| Jan15 | 0.000080 | 0.000128 | 100 | 0.456 | 38.46 |
| Jan23 | 0.000120 | 0.000090 | 100 | 0.451 | 57.14 |
| Jan29 | 0.000100 | 0.000140 | 100 | 0.520 | 41.66 |
| | | | 90 cm depth | | |
| Aug13 | | | PURE NUGGET EFFECT | | |
| Aug20 | | | PURE NUGGET EFFECT | | |
| Aug26 | | | PURE NUGGET EFFECT | | |
| Sep02 | | | PURE NUGGET EFFECT | | |
| Sep09 | | | PURE NUGGET EFFECT | | |
| Sep18 | | | PURE NUGGET EFFECT | | |
| Oct01 | | | PURE NUGGET EFFECT | | |
| Jan08 | 0.000090 | 0.000040 | 85 | 0.357 | 69.23 |
| Jan15 | 0.000098 | 0.000015 | 40 | 0.133 | 86.72 |
| Jan23 | 0.000120 | 0.000018 | 40 | 0.163 | 86.95 |
| Jan29 | 0.000100 | 0.000014 | 30 | 0.174 | 87.72 |

son for the measurements having been taken only in these 102 points was to allow measurements to be taken in the three depths on the same day. Even though bring an operational problem, results indicate that the sampling density used proved to be insufficient for an adequate characterization of the spatial variability.

Figures 4 to 5 show the semivariograms for the soil moisture data sampled in 2003 at 60 cm and in 2004 at 30, 60 and 90 cm, in which the weak dependence of these measurements can be seen, especially for 2003. For the results corresponding to the 60 cm in 2003, as compared with those corresponding to the summer months (December 2003, January and February 2004) there was an increase in the range of spatial dependence, from 90 to 100 m. Figure 6 shows the scaled semivariograms obtained according to Vieira et al. (1991), for all depths for 2003/2004, where it can be seen that for 60 cm there is stronger spatial dependence because the sill is more visible (Figure 6b) than in Figures 6a and 6c. In general, the semivariograms indicate that when the soil has lower water content the spatial dependence is weaker. The reason for this is probably because as the soil becomes dryer, some cracks may appear and cause randomness of the spatial



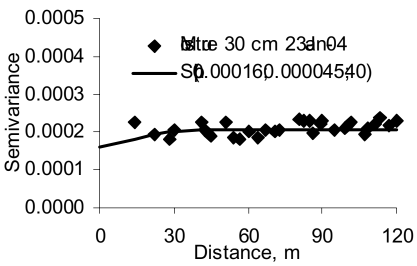

a) 60 cm 13-Aug-03 b) 60 cm 20-Aug-03 c) 60 cm 26-Aug-03

d) 60 cm 02-Sept-03 e) 60 cm 09-Sept-03 f) 60 cm 18-Sept-03

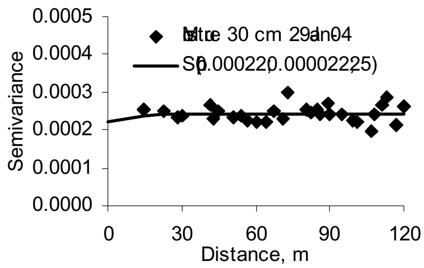
g) 60 cm 01-Oct-03 h) 60 cm 08-Jan-04 i) 60 cm 15-Jan-04

j) 60 cm 23-Jan-04 k) 60 cm 29-Jan-04 l) 30 cm 08-Jan-04

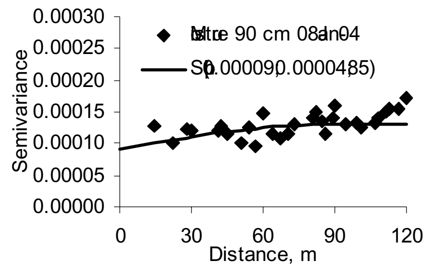
Figure 4 - Semivariograms for moisture content values.



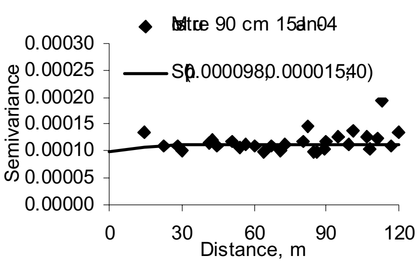

a) 30 cm 23-Jan-04



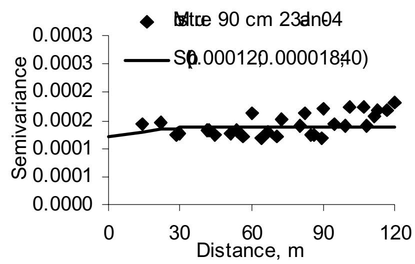

b) 30 cm 29-Jan-04



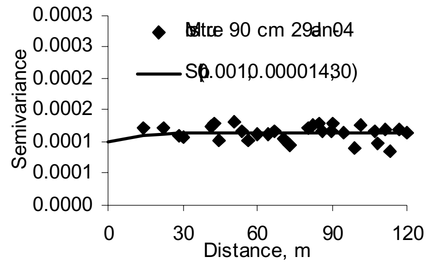

c) 90 cm 08-Jan-04




d) 90 cm 15-Jan-04

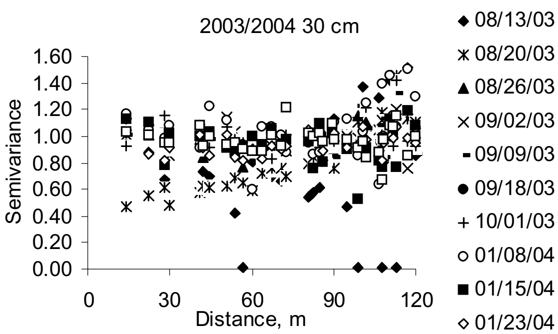



e) 90 cm 23-Jan-04

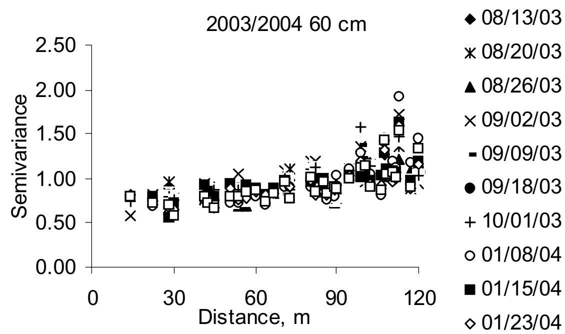



f) 90 cm 29-Jan-04

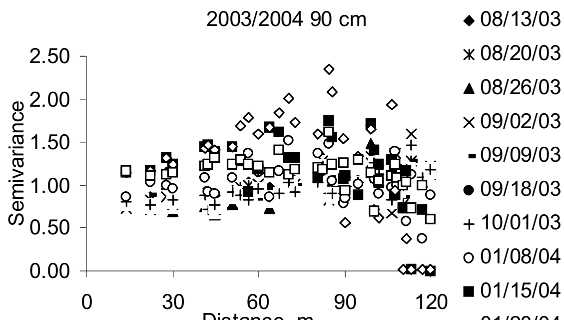
Figure 5 - Semivariograms for moisture content values.




a) 30 cm




b) 60 cm

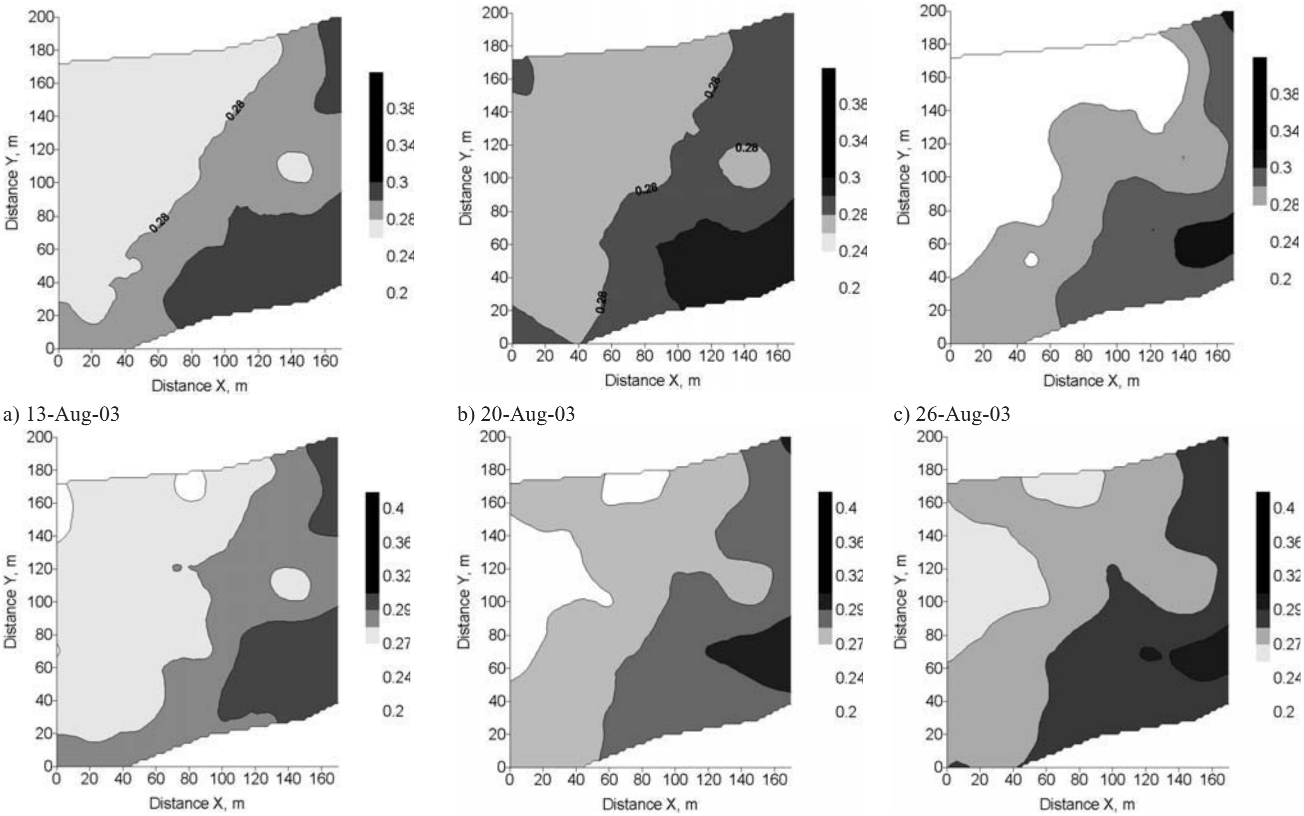



c) 90 cm

Figure 6 - Scaled semivariograms for moisture content values.

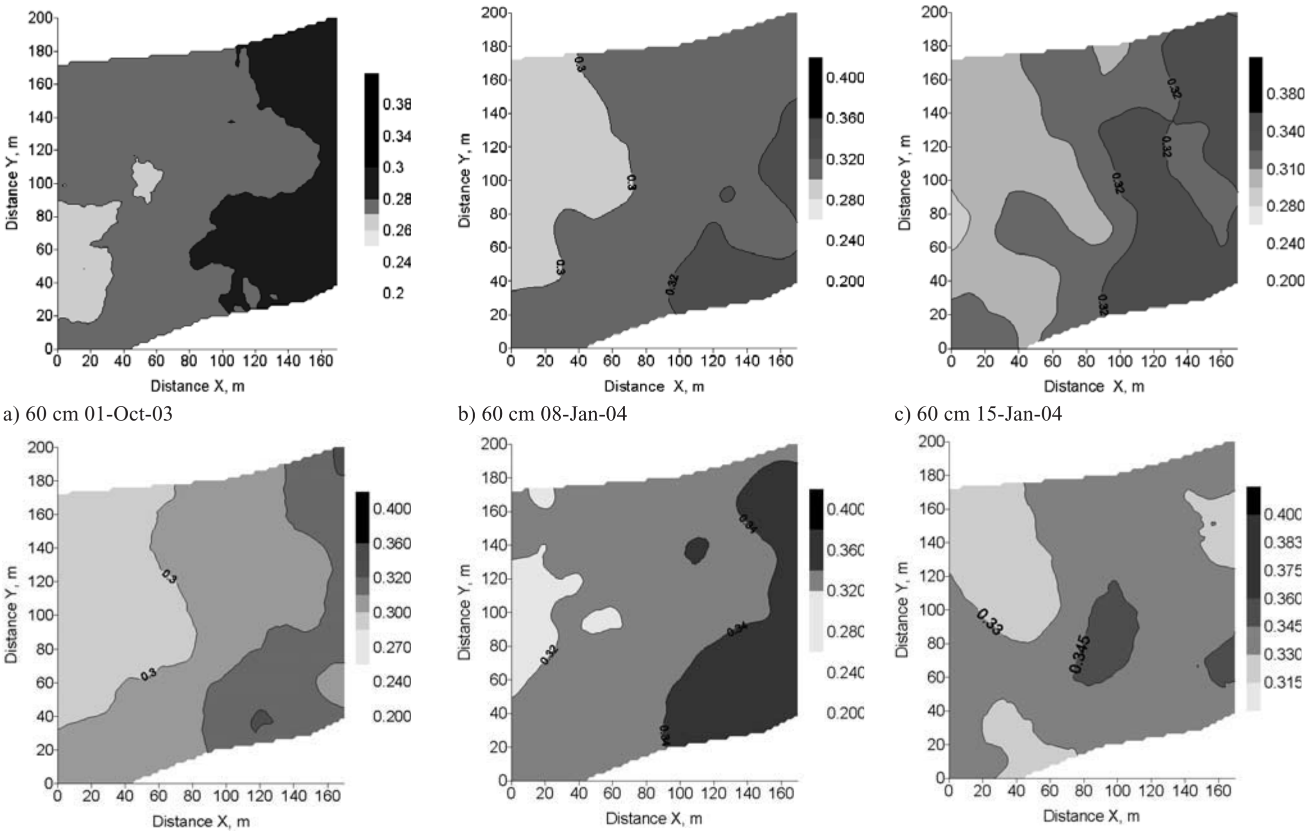
variation. Another reason is that when the soil has lower water content other soil properties, such as hydraulic conductivity, may affect this randomness because in this case the water content is not the only variable controlling the loss of water to the atmosphere.

The maps (Figures 7 to 9) showed that the right hand side of the area always had higher soil moisture contents than the left hand side which agrees with the findings of Vauchaud et al. (1985). The soil map for the Experimental Center shows a well developed structured soil in this right hand side of the



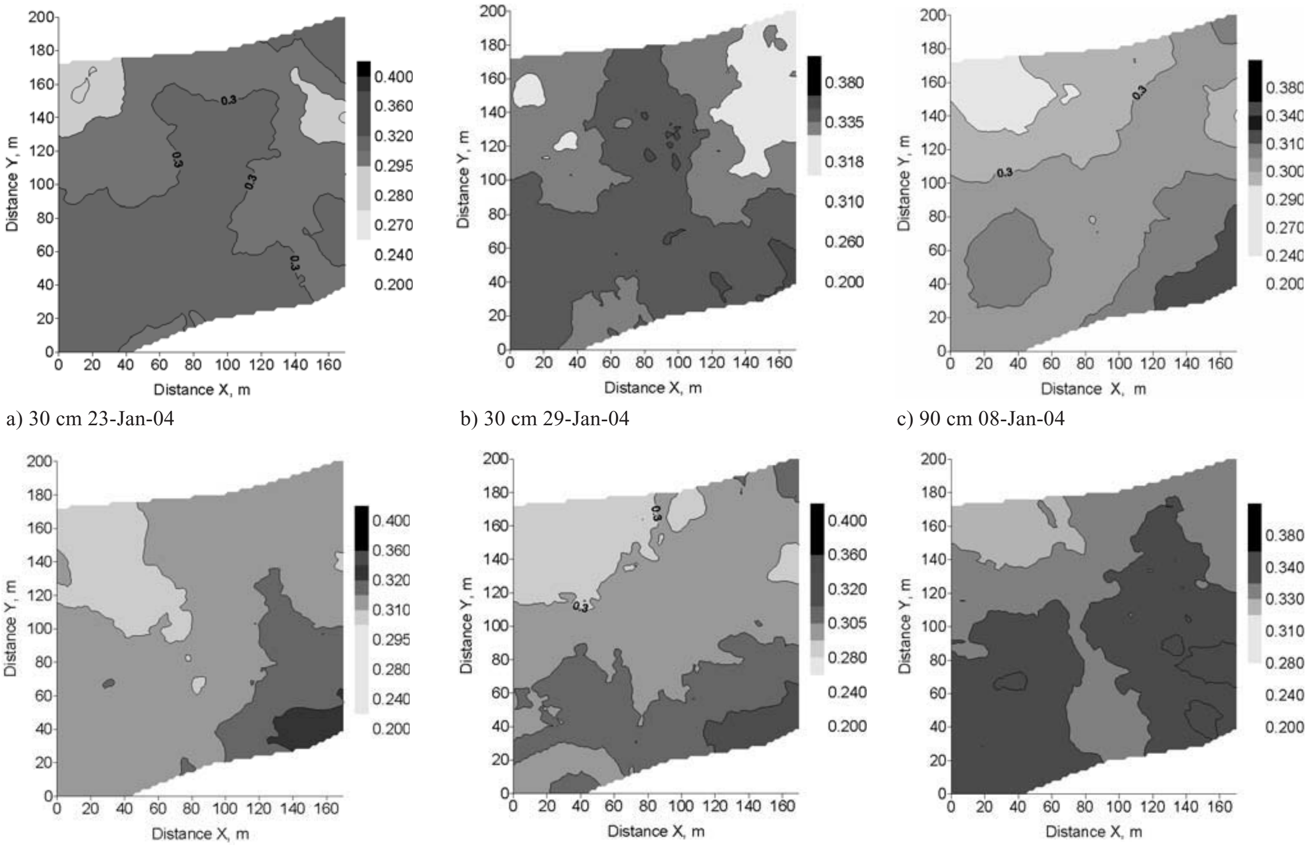

a) 13-Aug-03 b) 20-Aug-03 c) 26-Aug-03
d) 02-Sept-03 e) 09-Sept-03 f) 18-Sept-03

Figure 7 - Maps for moisture content values, 60 cm of the depth.




a) 60 cm 01-Oct-03 b) 60 cm 08-Jan-04 c) 60 cm 15-Jan-04
d) 60 cm 23-Jan-04 e) 60 cm 29-Jan-04 f) 30 cm 08-Jan-04

Figure 8 - Maps for moisture content values.




a) 30 cm 23-Jan-04 b) 30 cm 29-Jan-04 c) 90 cm 08-Jan-04

d) 90 cm 15-Jan-04 e) 90 cm 23-Jan-04 f) 90 cm 29-Jan-04

Figure 9 - Maps for moisture content values.

field. This may also be due to the fact that the lower right hand side of the field also presents lower altitude.

## CONCLUSIONS

Soil moisture content at the 60 cm depth presented a moderate spatial dependence with a range of 90 to 110 m, increasing from winter to summer, when the soil gains in water content.

Sampling density was insufficient for an adequate characterization of the spatial variability of soil moisture contents at the 30 and 90 cm depths, because correlated variation occurs at distances smaller than the 10m sampling.

The lower right hand side of the area always had higher soil moisture contents than any other side in the field.

## ACKNOWLEDGEMENTS

To ‘Instituto Agronômico’ (IAC) for infrastructure, to ‘Conselho Nacional de Desenvolvimento Científico e Tecnológico’ (CNPq) and ‘Fundação de Amparo à pesquisa do Estado de São Paulo’ (Fapesp) for fellowships and financial support.

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Received June 20, 2005
Accepted June 08, 2006