

Progress in Soil Science

Wenceslau Geraldes Teixeira
Marcos Bacis Ceddia
Marta Vasconcelos Ottoni
Guilheme Kangussu Donnagema
Editors

Application of Soil Physics in Environmental Analyses

Measuring, Modelling and Data
Integration

 Springer

Progress in Soil Science

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Editors

Wenceslau Geraudes Teixeira
Guilherme Kangussu Donnagema
Soil Physics
Embrapa Soils
Rio de Janeiro, RJ, Brazil

Marcos Bacis Ceddia
Soils Department
Rural Federal University of Rio de Janeiro
Seropédica, RJ, Brazil

Marta Vasconcelos Ottoni
Department of Hydrology
Companhia de Pesquisa de
Recursos Minerais (CPRM)
Geological Survey of Brazil
Rio de Janeiro, RJ, Brazil

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Foreword

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Chapter 4

Spatial Relationships Between Soil Water Content and Hydraulic Conductivity in a Highly Structured Clay Soils

Sidney Rosa Vieira, Célia Regina Grego, George Clarke Topp, and William Daniel Reynolds

Abstract The water, element essential for life, is present as a large reservoir in the soil. 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. The objective of this study was to assess the spatial and temporal variability of soil water content and its relationships with hydraulic conductivity. Soil water content was measured with a TDR equipment and the hydraulic conductivity was measured with a constant head well permeameter at 15 and 50 cm depth, in a nearly flat 1.2 ha field at the Central Experimental Farm of the Agriculture Canada, Ottawa. The soil is classified as a Rideau soil series, is primarily clay to silty clay texture. Sampling was made on a 10 m spacing square grid with 164 sampling points. Soil water content was measured on 33 dates during the frost free months in 1987, 1988 and 1989. The rate of change in soil water content was calculated for the periods which did not have any rain. The spatial variability was analyzed examining the descriptive statistical parameters, the parameters of the models fitted to individual semivariograms as a function of time and the maps obtained by kriging interpolation. It was concluded that soil structure played a very important role on the spatial distribution of hydraulic conductivity and water content. Temporal stability of water in the soil is quite different during the year probably because of the hydraulic conductivity role. Parabolic trend removal

S.R. Vieira (✉)
Agronomy Institute (IAC), Campinas, São Paulo, Brazil
e-mail: sidney@iac.sp.gov.br

C.R. Grego
Embrapa Satellite Monitoring, Campinas, São Paulo, Brazil

G.C. Topp
Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada,
Ottawa, ON, Canada

W.D. Reynolds
Greenhouse and Processing Crops Research Centre, Agriculture and Agri-Food Canada,
Harrow, ON, Canada

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worked well all through the year probably because of the topography. The behavior of spatial variability the rate of change in water of soil did not repeat in different times of the year studied.

Keywords: TDR • Temporal stability • Semivariogram • Geostatistics

4.1 Introduction

The water, element essential for life, is present as a large reservoir in the soil. Their distribution in space is variable due to fluctuations of other related properties, so knowledge of this variation in space and time becomes important in studies of soil physical properties. Soil water changes over landscape have been identified in several studies. Vauchaud et al. (1985) found temporal stability of frequency distribution of water in the soil, Kachanoski and De Jong (1988) studied the temporal persistence of spatial patterns of soil water storage, Vieira et al. (1997) reported on the scaling of spatial variability over time and Gonçalves et al. (1999) observed a temporal stability of soil water content stored in an irrigated area. During the last few decades geostatistical methods have been intensively used for descriptions of spatial variability in depth (Nielsen et al. 1983; Vieira et al. 1983; Vieira 2000; Grego and Vieira 2005; Vieira et al. 2008). Most of the authors reported that geostatistics is useful for evaluate the spatial dependence, use this spatial dependence to interpolate values for the places where they have not been measured, and to provide information to construct maps and design sampling strategies as a function of the spatial variability. The difference of statistics and geostatistics is that classical statistics require normality and spatial independence of the dates while geostatistics requires correlation and spatial dependence.

Variability in time, and in particular, with repeating patterns is being a challenge to soil research. 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 and De Jong 1988). Soil water content analyzed in consecutive sampling dates have been reported of 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 water 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. Scaling semivariograms of several variables measured over the same field provides a simple but powerful integration method (Vieira et al. 1988; Vieira et al. 1991; Vieira et al. 1997) in the sense that the more the semivariograms scale the more similar the variability of the corresponding variables are.

Therefore, if semivariograms scale, it indicates that not only the mean values and dispersion coefficients occur at the same locations but all variability repeats in time,

although the absolute of the models fitted samplings may be of. Thus, in order to an important calculate a semivariogram model different dates and r. The objective of

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- To use geostatisti hydraulic condu ct
- To analyze the ter and its relations v

4.2 Methodology

4.2.1 Study Area

The study was developed with clay loam to Agriculture Canada, and sixty four TDR water content were obtained on the same in-place at the same and kept there for 3 with the TDR method.

All water content time period. The triangle 110 m in the x-direction a 10 x 10 m grid with shown in Fig. 4.1.

The study period during the ground surface September 11, 14, 17 with different TDR in 13 and 30, June 06, September 02, 08, 11 were April 14, 18, 21 mm, during the study

although the absolute values may be different. Besides, the analysis of the parameters of the models fitted to the semivariograms as a function of the time of successive samplings may be of help in assessing the temporal stability of the spatial variability. Thus, in order to analyze temporal and spatial variability of water content it is important calculate and compare scaled semivariograms for different dates, compare semivariogram model parameters and construct and compare contour maps for different dates and variables.

The objective of this chapter was:

- To describe the spatial variability as well as the temporal stability of the spatial distribution for soil water content.
- To use geostatistics to evaluate the spatial variability of soil water content and of hydraulic conductivity.
- To analyze the temporal stability of the spatial dependence of soil water content and its relations with the soil hydraulic conductivity.

4.2 Methodology

4.2.1 Study Area and Soil Sampling

The study was developed in a Rideau clay loam soil (Gleyed Melanic Brunisol) with clay loam to clay surface texture, in the Central Experimental Farm of Agriculture Canada, Ottawa, with grasses vegetation maintained low. One hundred and sixty four TDR (time domain reflectometry) rods for measuring volumetric water content were installed. Therefore, soil water content measurements could be obtained on the same points as many times as wanted since the IDR rods remained in-place at the same points in the field. The TDR rods were installed at 45° angle and kept there for 3 years. All the soil water content contents measured were done with the TDR method according to Topp and Davis (1985).

All water content measurements over the field were collected within a two-hour time period. The triangular field, kept vegetated with natural pasture grass, measured 110 m in the x-direction (base) and 220 m in the y-direction (height), was divided into a 10 x 10m grid with 164 points. The grid and topographic map of the study area are shown in Fig. 4.1.

The study period extended from early September of 1987 until early May 1989 during the ground surface frost-free months. The dates of samplings in 1987 were September 11,14,17,21,24, and October 29 with two samplings on the same day with different TDR instruments. There were 19 samplings dates in 1988: May 06, 13 and 30, June 06, 13, 21 and 27, July 04, 15, 22 and 28, August 11, 18 and 25, September 02, 08, 15, 22 and 29, and October 06. The dates of samplings in 1989 were April 14, 18,21,25 and 28 and May 01. Figure 4.2 shows the precipitation in mm, during the study período

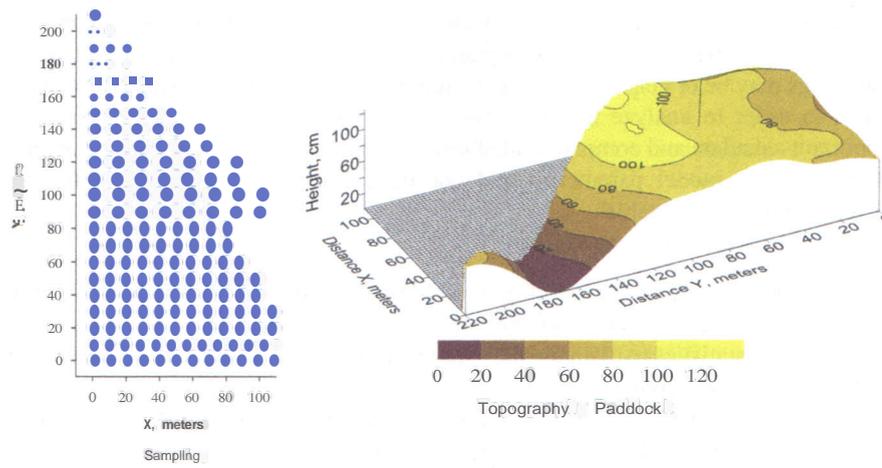


Fig. 4.1 Sampling scheme and topography of the area

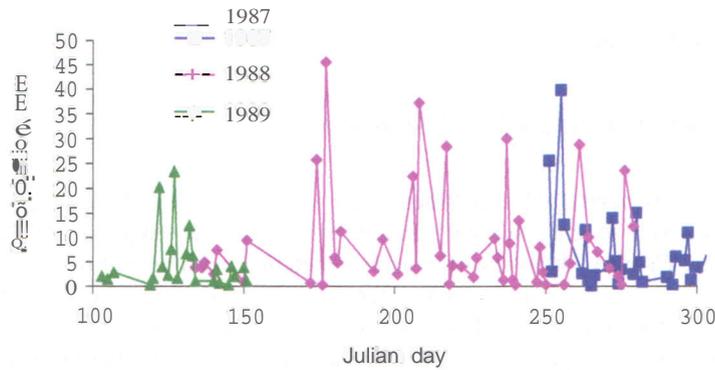


Fig. 4.2 Rainfall as a function of time during the years 1987 until 1989

The sampling dates were converted to Julian days in order to make the parameters plot a function of time during the year.

Figure 4.2 shows a distribution of rainfall during the entire research period for the three years. Except for a few peaks of very high rainfall most of them are somewhere around 5 and 10 mm. Therefore, except for some days right after the peaks of rainfall, it is expected that the major contribution for soil water content is the snow melt.

The field saturated hydraulic conductivity, K_{fs} , was measured in each one of the locations shown in Fig. 4.1 using the constant head well permeameter (Reynolds and Elrick 1986) and calculated using the one head approach as recommended by Reynolds et al. (1992). At the time the hydraulic conductivity were measured, TDR readings were made in each one of the 164 sampling points in order to have the initial soil water content.

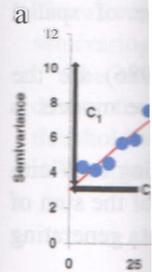


Fig. 4.3 (a) $\hat{\sigma}^2$ (variance) and σ^2

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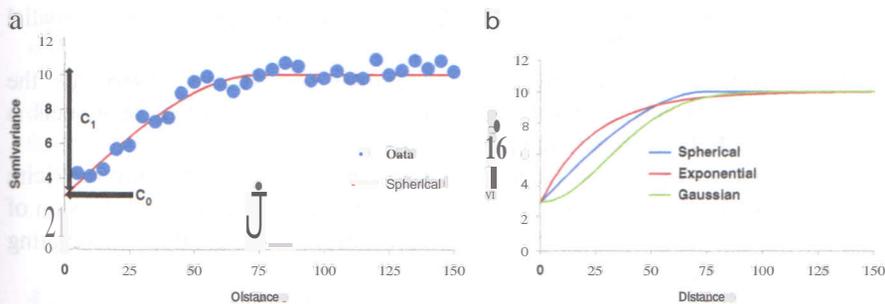


Fig. 4.3 (a) Characteristics of a typical semivariogram, with C_0 (nugget effect), C_1 (structural variance) and a (range); (b) Most commonly used models: spherical, exponential and Gaussian

4.2.2 Spatial Variability Theory

In order to be able to evaluate the spatial variability with geostatistics the basic requirements are: Cartesian coordinates, intrinsic hypothesis, semivariogram showing a well-defined sill and similarity between neighbors. The equations that represent hypothesis for geostatistics are:

$$E\{Z(x_i)\} = m \tag{4.1}$$

Where a random function $Z(x_j)$ is stationary of order two if the expected value, $E\{Z(x)\}$ exists and does not depend on the position x .

In addition to the condition in Eq. 4.1, the Eq. 4.2 represent a random function $Z(x_j)$ when is a intrinsic hypothesis. The increment $[Z(x_j) - Z(x_j+h)]$ has a finite variance, and does not depend on x_i for all vectors h .

$$VAR[Z(x_i) - Z(x_i + h)] = E[Z(x_i) - Z(x_i + h)]^2 \tag{4.2}$$

The function $\gamma(h)$ is the semivariogram (Matheron 1963) estimated by

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \tag{4.3}$$

where $N(h)$ is the number of pairs of measured values $Z(x_j), Z(x_j+h)$, separated by a vector h (distance).

The main characteristics of a semivariogram are shown in Fig. 4.3a.

Experimental semivariograms need to be fitted to some mathematical model which must meet the criteria of conditional positive definiteness Matheron and Webster (1986). Amongst all the variety of models which satisfy that condition, the fitting parameters that describe them are: the nugget effect C_0 , the sill $(C_0 + C_1)$, C_1 is the

structured variance coefficient to be defined later), and the range of spatial dependence a .

The models most frequently used (McBratney and Webster 1986) are the spherical, the exponential and the gaussian models. A graph of these models is shown in Fig. 4.3b for illustration purposes.

When data shows a trend (semivariogram without a sill), according to Vieira et al. (2010b), an alternative is fit a trend surface using minimization of the sum of squares of the deviations and subtract this surface from the original data generating a residual variable.

For instance, the equation for a parabolic trend surface is:

$$\hat{Z}_{est}(x, y) = A_0 + A_1X + A_2Y + A_3X^2 + A_4XY + A_5Y^2 \quad (4.4)$$

Where $\hat{Z}_{est}(x, y)$ is a estimate value for parabolic trend surface to measured values (A_0, \dots, A_5Y^2).

Thus, the residuals, $Z_{res}(x, y)$, can be calculated

$$Z_{res}(x, y) = Z(x, y) - \hat{Z}_{est}(x, y) \quad (4.5)$$

With the objective of comparing the variability of different samplings, Vieira et al. (1997) proposed a scaling technique for the semivariogram expressed by:

$$y_{sch} = yL^a, L = 1, 2, \dots, m \quad (4.6)$$

Where a is the scaling factor for semivariance (y) and m is the number of measured variables.

The scale factor a , is a constant that can take the value of the calculated variance, the sill (the highest value of the semivariance) or the square of the mean values. The scaling concept proposed by Vieira et al. (1997) may be helpful in the analysis of the temporal stability of the spatial variability of soil water content corresponding to different sampling dates for the same location. Within each data set (year of sampling) the scaled semivariograms for all sampling dates can be plotted together in order to make comparisons and verify if and when the spatial variability loses temporal stability. When data of several dates coalesce into a unified semivariogram structure, it is possible to take advantage of variables having the same spatial structure and, hence, reduce the number of semivariograms needed to analyze and draw interpretations regarding their spatial variability.

Two facts are very important about the above theoretical concepts: (i) The semivariogram $\gamma(h)$ is assumed to be isotropic, i.e., either there is no significant anisotropy or there is a transformation to remove the anisotropy before scaling is applied; (ii) $\gamma(h)$ can take the value of the calculated variance $\text{Var}(z)$ no matter whether it represents the true variance or not, since the scaling factor is simply a number chosen to make the semivariograms coalesce into a single curve. The reason why scaled semivariograms may provide an adequate way to analyze temporal evolution of the spatial variability is that it will be noticeable when the spatial variability pattern changes, and thus the possible cause can be examined.

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Hydraulic γ 50 em (10)
Soil water CON

ic conductivity

	RMSE	Dist
58	1.65	61
18	2.41	61
51	1.12	51
57	4.67	51

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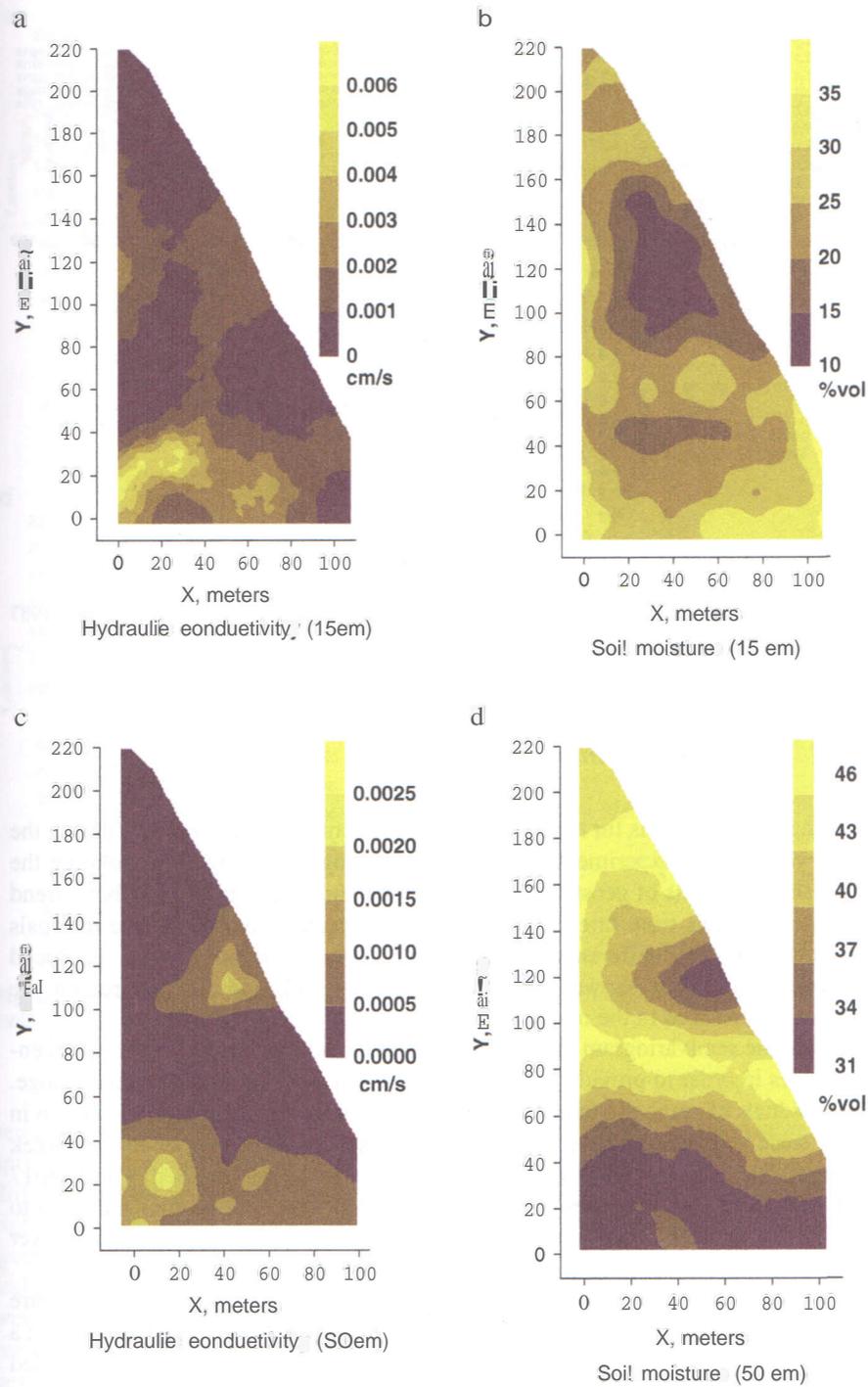


Fig. 4.5 Maps for hydraulic conductivity (a and b) and soil water content (c and d) at 15 and 50 em depth

Therefore, scaling is used in this paper only for the comparison between semivariograms for different samplings on the same field,

The examination of the spatial variability for soil water content as the time during the year progresses may reveal information about some water content threshold value at which the soil hydraulic conductivity begins to cause changes in the spatial variability patterns.

4.2.3 Water Content Change Over Successive Sampling Dates

The rate of change of water content over time, $\Delta(\theta_i, \theta_j)$ can be expressed as the difference in water content (% vol.) measured at times i and j divided by the time interval (day).

$$\Delta(\theta_i, \theta_j) = (\theta_i - \theta_j) / (t_i - t_j) \quad (4.7)$$

The rate of change in water content over time, $\Delta(\theta_i, \theta_j)$ was calculated for the period when there was no rain. Therefore, all the change in water content was caused strictly by water loss to the atmosphere. When the soil has enough water to satisfy the atmospheric demand without restrictions, assuming that the energy available for the evaporation process is not variable in space at the scale of the field under study (10x220 m), then the variability of the evaporation rate is likely to reflect the soil surface conditions. Besides, because the soil cover constituted primarily of pasture grasses and it was maintained at low height, then not much spatial variability due to vegetation evaporation is expected for this field.

4.3 Result and Discussion

The descriptive statistical moments for hydraulic conductivity at 15 and 50 cm depths and soil water content measured in 164 points are shown in Table 4.1. The hydraulic conductivity for the two depths showed very high coefficients of skewness and

Table 4.1 Descriptive statistical moments for hydraulic conductivity and soil water content measured at 15 and 50 cm depth

Variable	Num	Mean	Variance	CV	Min	Max	Skew	Kurt
Hydraulic Conductivity - 15 cm (logs)	164	-677	291	-2,520	-1,135	-285	009	-042
Soil water content - 15 cm	164	2,372	3,520	2,502	1,170	3,640	-012	-065
Hydraulic Conductivity - 50 cm (logs)	164	-826	270	-1,991	-1,340	-495	-079	016
Soil water content - 50 cm	164	3,951	5,174	1,821	1,690	5,360	-033	-038

Table 4.2 Semivariogram model parameters for hydraulic conductivity and soil water content measured at 15 and 50 cm depth

Variable	Model	C_0	C_1	a	λ	RMSE
Hydraulic Conductivity 15 cm (logs)	Exponential	228	087	7,211	045	0.005
Soil water content 15 cm	Spherical	000	2,908	7,000	080	0.139
Hydraulic Conductivity 50 cm (logs)	Spherical	052	203	7,000	084	0.008
Soil water content 50 cm	Gaussian	1,670	2,997	7,000	094	0.080

kurtosis. For that reason it was decided to work on the logs rather than the original values. This transformation, although it is always better not to need it, it does make the coefficients of skewness and kurtosis to approach 0 (zero). In this condition the data has a frequency distribution close to the normal and it makes the analysis easier according to Vieira (2000).

It can be seen in Table 4.1 that mean hydraulic conductivity is much higher at 15 cm than at 50 cm depth which is caused by the strong blocky structure at depths near the surface and massive structure at deeper depths. On the other hand the moisture content is much higher at 50 cm than at 15 cm depth. The coefficients of variation are within the normal range expected for physical soil data of this type. Similar results have been reported by Vieira et al. (1988). One aspect of Table 4.1 which is initially difficult to explain is the large range in water content (approximately 25 % for 15 cm depth and 36 % for 50 cm depth). It should be considered that after the snow melt redistribution of water not very much change should be expected for moisture content at 50 cm depth this without a crop growing cultivated in this area.

The hydraulic conductivity and soil water content at 15 and 50 cm depth showed enough spatial dependence to influence on the interpolation of values at any spacing finer than that they were measured (10 m) without bias and with minimum variance, as the parameters for the models fitted to the semivariogram (Table 4.2) indicate. The range of spatial dependence was 70.0 m or more for all of them. The spatial dependence for the hydraulic conductivity for the 15 cm depth was somewhat weak due to the randomness of the macro pores at the surface layer which causes a lot variable in the water flow.

The Fig. 4.4a, b show the scaled semivariograms for hydraulic conductivity and soil water content, respectively, at 15 and 50 cm depth. The Rideau soil at this site has a very strong blocky structure at the first 25 cm. On the other hand, at 50 cm depth this soil has a very massive structure or no structure at all. Therefore, at 15 cm depth the water moves much faster in between the structure blocks while the soil water content is mostly retained inside the blocks. That is the main reason why the scaled semivariograms for 15 cm depth are so different because they represent different soil physical processes. On the other hand, at 50 cm depth the water moves faster where there is more water and for that reason, the spatial variability of soil water content is so similar to that of the hydraulic conductivity. According to Vieira et al. (1997) the soil physical process is the main reason why scaled semivariograms are so alike.

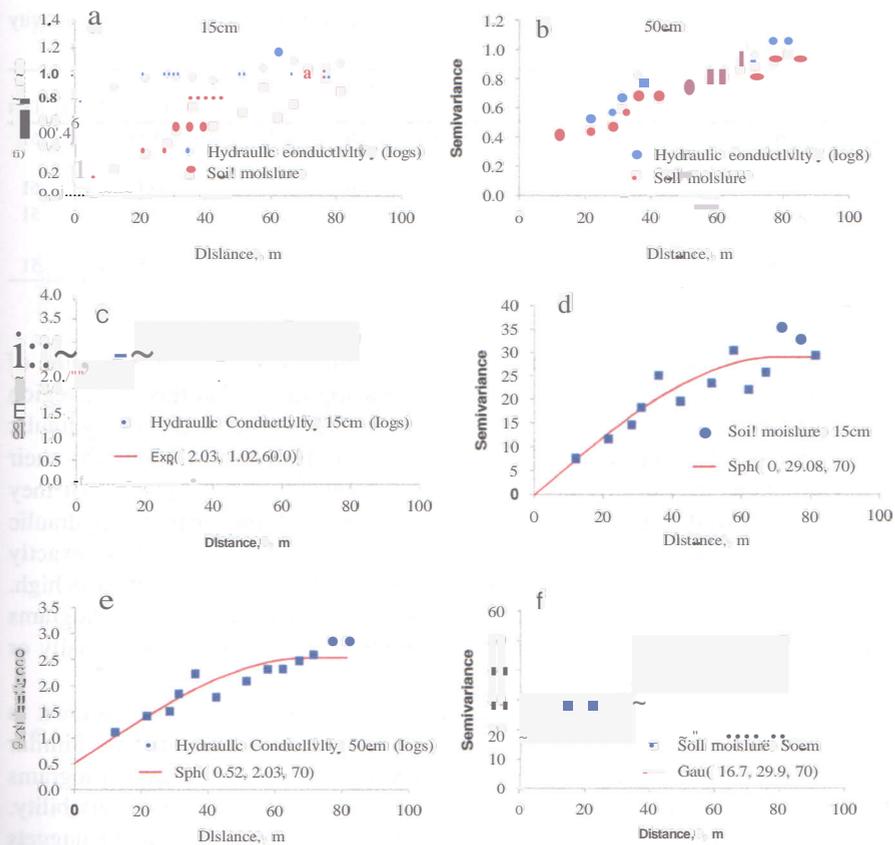


Fig. 4.4 Semivariograms for hydraulic conductivity and water content: (a) sealed semivariogram for hydraulic conductivity and water content at 15 cm depth; (b) sealed semivariogram for hydraulic conductivity and water content at 50 cm depth; (c) semivariogram for hydraulic conductivity (logs) at 15 cm depth; (d) semivariogram for water content at 15 cm depth; (e) semivariogram for hydraulic conductivity (logs) at 50 cm depth; (f) semivariogram for water content at 50 cm depth.

Figure 4.4c-f., show that the models chosen to fit the semivariograms worked very well for all of them as the models follow the experimental semivariograms with strong spatial dependence as it is also indicated by the r^2 values shown in Table 4.2.

The spatial dependence expressed by the semivariograms parameters shown in Table 4.2 are validated by the jackknifing procedure whose parameters are shown in Table 4.3. According to Vieira et al. (2010a) the main parameters in Table 4.3 are the mean error and the variance of the errors, which should be, respectively, 0 (zero) and 1 (one). Thus it can be concluded that all 4 semivariograms are validated as their parameters approach the ideal values.

The maps for hydraulic conductivity and soil water content measured at the time the hydraulic conductivities were measured are shown in Fig. 4.5. The region in the

Table 4.3 Jack knifing results for the semivariogram model parameters for hydraulic conductivity and soil water content measured at 15 and 50 cm depth

Variable	Neighbors	A	b	c	Mean error	Variance of errors	UK	RMSE	Dist
Hydraulic Conductivity 15 cm (logs)	16	-6.17	0.09	0.25	0.00	0.97	-1.68	1.65	61
Soil water content 15 cm	16	4.19	0.82	0.91	0.00	1.08	-0.18	2.41	61
Hydraulic Conductivity 50 cm (logs)	12	-3.91	0.53	0.73	-0.01	1.24	-0.51	1.12	51
Soil water content 50 cm	12	17.93	0.55	0.76	0.00	1.12	-0.57	4.67	51

field with low water content values for 15 cm depth falls exactly in the region of higher topographic heights (Fig. 4.1b). It is amazing to see that this same region had also low soil water content for the 50 cm depth. The maps for hydraulic conductivity and water content for 15 cm depth illustrate the reason why their semivariograms are so different when they are scaled which simply is that they represent a very distinct variability. On the other hand, the maps for hydraulic conductivity and soil water content for 50 cm depth have variability almost exactly the reverse, with low values of conductivity where the soil water content is high. That was exactly the idea reported by Vieira et al. (1997) that if the semivariograms scale well it is an indication that the two variables either vary almost equally or almost opposite to each other.

The scaled semivariograms for rate of change in soil water content shown in Fig. 4.6 indicate that the variability for water loss is not stable in time. Similar results were found by Grego et al. (2006) showing that the scaled semivariograms for soil water content may be used to indicate time stability of the spatial variability. Five out of twenty nine semivariograms showed pure nugget effect. All the nuggets happened after a large previous rain. Twenty three models were spherical and one was exponential.

The in Fig. 4.7 show that the rate of change of water content does not repeat in time. It should be noticed that these rate of change in water content are for the three years period which means that there might be climate variability involved in these numbers. The intervals at the beginning of the year (April, May) probably reflect the amount of snow cover. Beginning of May 1988 and beginning of April 1989 seem to agree with each other probably of snow melt. The two rates for 1988 (05/30-06/06 and 06/06-13/06) do not seem to have anything in common and rather are completely the opposite. Beginning of September 1987 seem to agree with end of April 1989 but are not related to topography and/or surface texture but rather with the hydraulic conductivity at 50 cm depth. Buttafuoco et al. (2005) showed a high temporal correlation between the soil water contents measured at different times, declining as the interval between the observations increases. The autumn rain events on dry soil produced an erratic distribution pattern of water in the soil and the kriged maps of soil water revealed the dynamics of soil water redistribution owing to evapotranspiration or rainfall.

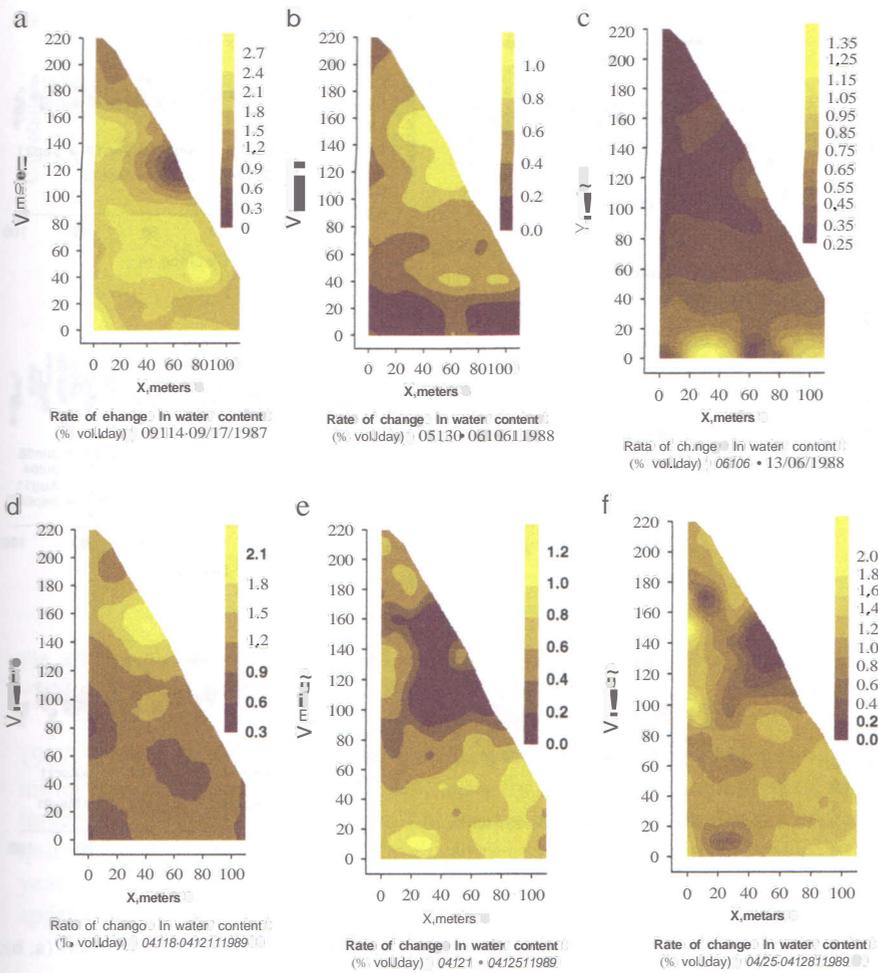


Fig.4.7 Maps for rate of change in soil water content for the 6 periods without rain in 1987 (a), 1988 (b, c) and 1989 (d, e, f)

semivariograms was similar for summer and fall, and different for winter and spring. In the present work it appears that the spatial behavior for water content is different at the beginning and at the end of the year. Even for a short period of time right after snow melt (March or April) the spatial behavior seem to change from one week to the next. It seem like two weeks at this time of the year is the limit for the stability of spatial variability. It should be noticed also that the semivariograms were already close to each other before the scaling (Fig. 4.8). The parabolic trend removing process produced semivariograms with very well defined sills for all three years,

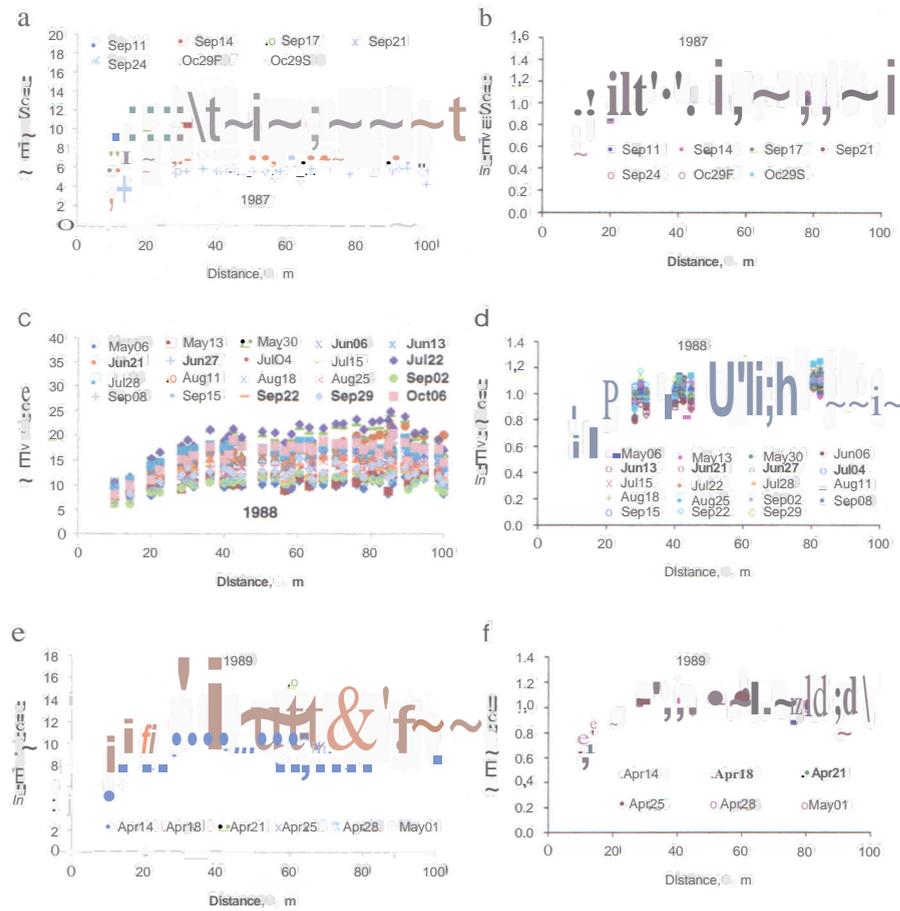


Fig.4.8 Non scaled and scaled semivariograms for soil water content for the 3 years: 1987 (a, b); 1988 (c, d); 1989 (e, f)

4.3.2 Soil 'memory'

The length of time that soil water content expresses correlation with soil water content at an initial time is what may be called as soil 'memory'. The reason for this is in the question 'how long does the soil "remember" the initial soil water content?' In order to illustrate this idea with these three year data, the correlation between water content at some initial time and subsequent soil water content was calculated and plotted in the graphs in Fig. 4.9. For comparison purposes, these calculations were done for both the original values and the residuals of a parabolic trend. The initial times were September/11, May/06 and April/14, respectively for

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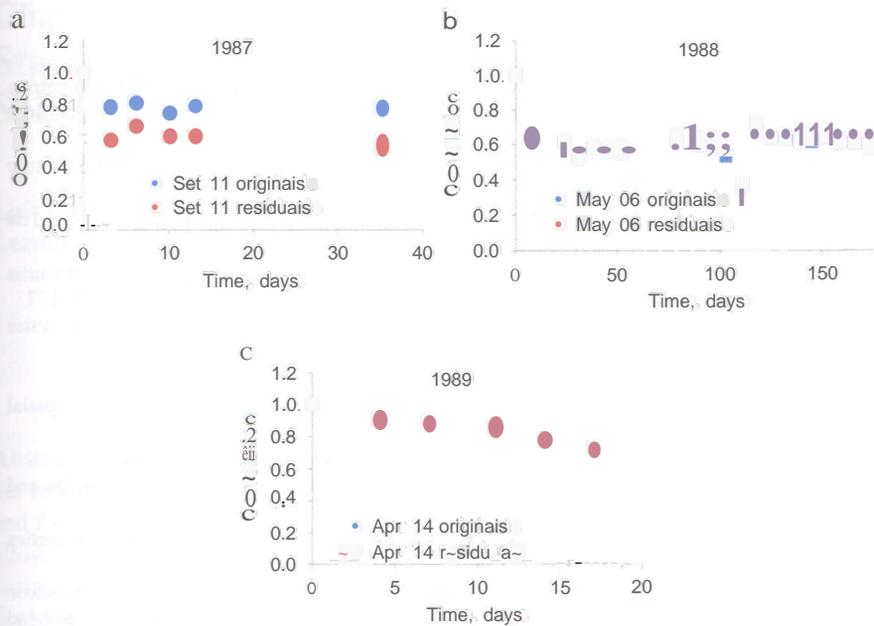


Fig.4.9 Persistence of correlation between soil water content for the initial sampling date and soil water content in subsequent dates in 1987 (a), 1988 (b) and 1989 (c)

1987, 1988 and 1989. The correlation between any soil water content and the initial one was never lower than 0.6, even for 1988 when the length of time is larger than 150 days. That means that the time stability of the water content is quite high. For 1989, when the data covers only the beginning of the frost free year (April) and the soil is very wet due to snow melt, the correlation remains at approximately 0.8.

4.4 Conclusions

The following conclusions can be extracted in accordance with the text:

- ~ Soil structure played a very important role on the spatial distribution of hydraulic conductivity and water content.
- ~ Temporal stability is quite different during the year probably because of the hydraulic conductivity role.
- Parabolic trend removal worked well all through the year probably because of the topography.
- Rate of change in water content with time did not repeat variability in different times of the year.
- ~ Correlation of water content remains for a long time (more than 100 days).
- ~ Unique field topography and surface texture may have been the reason for the results.

References

- Ávila LF, Mello CR, Mello JM, Silva AM (2011) Padrão espaço-temporal da umidade volumétrica do solo em uma bacia hidrográfica com predominância de Latossolos. *Rev Bras Ciênc Solo Viçosa* 35:1801-1810
- Buttafuoco O, Castrignano A, Busoni E, Dimase AC (2005) Studying the spatial structure evolution of soil water content using multivariate geostatistics. *J Hydrol* 311:202-218
- Oonçalves ACA, Folegatti MV, Silva AP (1999) Estabilidade temporal da distribuição espacial da umidade do solo em área irrigada por pivô central. *Rev Bras Ciênc Solo* 23:55-164
- Oregó CR, Vieira SR (2005) Variabilidade espacial de propriedades físicas do solo em uma parcela experimental. *Revista Brasileira de Ciência do Solo (Impresso)*. Viçosa 29:169-177
- Oregó CR, Vieira SR, Antonio AM, Della Rosa SC (2006) Geostatistical analysis for soil water content under no tillage cropping system. *Sci Agric* 63:341-350
- Journel AO, Huijbregts CJ (1978) Mining geostatistics. Academic, San Diego, 600 p
- Kachanoski RO, De Jong E (1988) Scale dependence and the temporal persistence of spatial patterns of soil water storage. *Water Resour Res* 24:85-91
- Matheron O (1963) Principles of geostatistics. *Econ Geol (Lancaster)* 58:1246-1266
- Mcbratney AB, Webster R (1986) Choosing functions for semivariograms of soil properties and fitting them to sampling estimates. *J Soil Sci* 37:617-639
- Nielsen DR, Tillotson PM, Vieira SR (1983) Analysing field - Measured soil water properties agricultural. *Water Manage* 6:63-109
- Reynolds WD, Elrick DE (1986) A method for simultaneous in situ measurements in the vadose zone of field saturated hydraulic conductivity, sorptivity, and the conductivity-pressure head relationship. *Ground Water Monit Rev* 6:84-95
- Reynolds WD, Vieira SR, Topp OC (1992) An assessment of the single-head analysis for the constant head well permeameter. *Can J Soil Sci (Ottawa)* 72:489-501
- Topp OC, Davis JL (1985) Measurement of soil water content using time domain reflectometry (TDR): a field evaluation. *Soil Sci Soc Am J* 49:574-582
- Vauchaud O, De Silane P, Balabanis A, Vauclin M (1985) Temporal stability of spatially measured soil water probability density function. *Soil Sci Soc Am J* 49:822-827
- Vieira SR (2000) Uso de geoestatística em estudos de variabilidade espacial de propriedades do solo. In: Novaes RF (ed) *Tópicos em Ciência do Solo*. Sociedade Brasileira de Ciência do Solo, Viçosa, pp 3-87
- Vieira SR, Hatfield JL, Nielsen DR, Biggar JW (1983) Geostatistical theory and application to variability of some agronomical properties. *Hilgardia* 51(3):1-75
- Vieira SR, Reynolds WD, Topp GC (1988) Spatial variability of hydraulic properties in a highly structured clay soil. In: *Validation of flow and transport models for the unsaturated zone Ruidoso*. Conference Proceedings Ruidoso, Novo Mexico: Department of Agronomy and Horticulture, New Mexico State University, pp 471-483
- Vieira SR, Lombardi Neto F, Burrows IT (1991) Mapeamento da chuva máxima provável para o Estado de São Paulo. *Rev Bras Ciênc Solo* 15:93-98
- Vieira SR, Nielsen DR, Biggar JW, Tillotson PM (1997) The scaling of semivariograms and the kriging estimation. *Rev Bras Ciênc Solo* 21:525-533
- Vieira SR, Oregó CR, Topp OC (2008) Analyzing spatial and temporal variability of soil water content. *Bragantia* 67:463-469
- Vieira SR, Carvalho JRP, Ceddia MB, Paz Oonzález A (2010a) Detrending non stationary data for geostatistical applications. *Bragantia* 69(Suplemento): 1-8
- Vieira SR, Carvalho JRP, Paz Oonzález A (2010b) Jack knifing for semivariogram validation. *Bragantia* 69(Suplemento):97-105

Progress in Soil Science

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Application of Soil Physics in Environmental Analyses

Measuring, Modelling and Data Integration

The importance to preserve soil and water is widely recognized. Soil physics has grown considerably in the last years, however, those advances are thoroughly dispersed. In this volume, the authors will bring together the effectiveness of new field and lab sensors and the state-of-the-art in modeling and data analysis. The topics have been divided as follows: **Part 1** - Integrating data in soil physics proposes re-establishing the knowledge chain, linking tacit knowledge to cutting edge science. The use of field soil data or what has been called hydro pedology, is discussed and exemplified. **Part 2** - Data analysis in soil physics and pedotransfers functions presents the analysis of data in state-space and geostatistical approaches. **Part 3** - Different approaches to characterize soil physical quality indicators is focused on new techniques used to characterize, map and interpret soil physical parameters. The challenge of assessing soil physical quality is discussed from the simplest to the most complex indicators. **Part 4** - Sensors and monitoring in soil physics centers the discussion on equipment and sampling techniques for monitoring soil physical parameters. Technological advances are addressed, such as X-ray tomography, which provides a means to evaluate pore topological properties in a noninvasive way. A comparison with *in situ* and remotely sensed data of soil moisture and limitations in using these data for hydrological modeling are also discussed. **Part 5** - Creating data bases and models applied to soil physics discusses alternative approaches for modeling water flow and solute transport in the vadose zone. A review of multi-component solute transport models and examples of their use in agricultural and environmental applications are given. The phenomenon of dynamic non-equilibrium in soil water flow is discussed as the need of a paradigm change. Root water uptake is also covered with advanced approaches and the last two chapters address the challenges to develop soil data bases.

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