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PERSISTÊNCIA TEMPORAL DO PADRÃO DE ARMAZENAMENTO DE ÁGUA EM SOLO ARGILOSO CULTIVADO COM FEIJÃO

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1 RESUMO

O objetivo do presente trabalho foi avaliar o armazenamento de água no perfil do solo, ao longo do tempo, a partir do aporte de água via irrigação e a persistência de um padrão desta variável no domínio espaço-temporal. A área experimental possui dimensões de 6,0 m de largura e 24,0 m de comprimento e está localizada na região Noroeste do estado do Paraná com solo caracterizado como Nitossolo Vermelho distroférrico. Foi semeado feijão em sistema de plantio direto com espaçamento 0,5 m x 0,1 m. A irrigação foi realizada empregando-se um sistema de aspersão convencional fixo com aspersores espaçados à 6 metros. O armazenamento de água foi monitorado por intermédio de 136 sondas de TDR instaladas entre 0 e 0,20 m de profundidade, sendo 88 sondas em malha regular e 48 com amostragem aninhada desbalanceada. A lâmina aplicada foi mensurada por meio de 88 coletores dispostos na superfície do solo ao lado das sondas da malha regular. Os dados foram submetidos à análise estatística descritiva e análise geoestatística. Os resultados evidenciaram que a uniformidade de aplicação de água não influenciou no padrão de armazenamento de água no solo. O armazenamento de água no solo apresenta estrutura de dependência espacial moderada.

Palavras-chave: geoestatística, uniformidade de aplicação, TDR.

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TEMPORAL PERSISTENCE OF WATER PATTERN STORAGE IN CLAYEY SOIL CULTIVATED WITH BEAN

2 ABSTRACT

The objective of the present work was to evaluate soil water storage (SWS) in the soil profile, over time, from the supply of water via irrigation and the persistence of a pattern of this variable in the space-time domain. The experimental area is 6.0 m in width and 24.0 m in length and is located in the Northwest region of the state of Paraná. Its soil is characterized as Dystroferric Red Nitosol. Beans were sown in a no-tillage system with 0.5 m x 0.1 m spacing. Irrigation was performed using a conventional fixed sprinkler system with sprinklers spaced 6 meters apart.

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Soil water storage was monitored using 136 TDR probes installed from 0 to 0.20 m deep, with 88 probes in regular mesh and 48 in an unbalanced nested sampling. The applied water depth, applied by sprinkler irrigation, was measured using 88 collectors arranged on the soil surface next to the regular mesh probes. The data were submitted for descriptive statistical analyses and geostatistical analysis. The results showed that the uniformity of water application did not influence the pattern of water storage in the soil. Soil water storage shows a moderate spatial dependence structure.

Keywords: geostatistics, uniformity of application, TDR.

3 INTRODUCTION

Water is an indispensable resource for animal and plant life. Faced with restrictions on water availability, high energy costs (LÓPEZ-MATA *et al.*, 2010), and market competition and demands, agriculture is increasingly aiming to adopt strategies for the production of consumer goods with greater technical and economic efficiency, taking into account the global concern for environmental protection, especially with regard to the use and conservation of water resources (PRADO; COLOMBO, 2013; MANTOVANI *et al.*, 2013).

One of the most important parameters for evaluating an irrigation system and implementing management practices is the uniformity of water application, which is quantified via uniformity coefficients (TOLEDO; SOUZA; ALBUQUERQUE, 2017). However, uniformity is often assessed only at the soil surface via rain gauges, assuming that it represents the uniformity of the water distribution throughout the soil profile.

Several studies (GONÇALVES *et al.*, 2010; HARA *et al.*, 2019; HARA *et al.*, 2020; LEMOS FILHO; BASSOI; FARIA, 2016; TORRES *et al.*, 2016) have shown that soil water storage varies in space and that its storage capacity and water availability for plants depend, to some extent, on intrinsic soil factors. Thus, it is necessary to address the uniformity of water application in the soil and, simultaneously, the uniformity of water storage so that irrigation management can be carried out with greater efficiency and lower costs (GUIMARÃES *et al.*, 2010).

Describing the spatial distribution pattern of soil water storage depends on soil moisture data obtained in space and repeated over time. The *time domain reflectometry (TDR) technique* enables these moisture data to be obtained, enabling the monitoring, understanding, and description of soil water dynamics. Geostatistical tools are necessary to understand this process, as they describe the spatial variability of soil water storage values on the basis of spatial continuity modeling, allowing the individual characterization of the subareas to be treated within the studied domain. As highlighted by Ferreira *et al*. (2016), mapping the spatial variability of soil physical–hydraulic properties is essential for rational, accurate, and sustainable management of irrigated areas.

In this context, the hypothesis was formulated that the uniformity with which water is applied to the surface of a cultivated clay soil has little effect on the uniformity of the water storage distribution in the soil profile explored by the crop's root system. Therefore, the objective of this study was to evaluate the spatial distribution of water storage in the profile of a clay soil in the region explored by the bean root system over time during the drying process, on the basis of water input via irrigation with different application uniformities, and to evaluate the persistence of a pattern in the spatiotemporal domain.

4 MATERIALS AND METHODS

The experiment was conducted in the municipality of Maringá, Paraná, at an altitude of 540 m and geographic coordinates of 23°25' South latitude and 51°57' West longitude. The soil in the experimental area is characterized as a dystroferric red nitrate with a clayey texture. The soil particle size composition is 122.6 g kg $^{-1}$ of sand, 120.6 g kg $^{-1}$ of silt, and 756.8 g kg $^{-1}$ of clay (HARA *et al.*, 2019).

The experimental area was delimited with dimensions of 6.0 m wide and 24.0 m long, considering the x- and y-axes, respectively. The entire area was covered with mulch originating from the desiccation of the *Brachiaria ruziziensis crop*. The soil was not fertilized, which was done to allow the crop to express the inherent characteristics of the soil during its development and production. The common carioca bean crop, cultivar Flor Diniz, was sown manually in a no-tillage system with a spacing of 0.5 m × 0.1 m. Sowing took place in July, and harvesting occurred in October, with a 90-day cycle with a water consumption of 328.27 mm.

To monitor the soil water storage pattern at the depth of the crop root system, TDR probes were installed within the experimental area in the 0.0 to 0.20 m layer, arranged at a 3.0 m × 24.0 m boundary, and spaced 2.0 m apart, as shown in Figure 1. As a criterion for installing the probes, two sampling systems were adopted, in which 88 probes were installed following a regular grid sampling system and 48 probes following an unbalanced nested sampling system (BADR; DURRANI, 1993; WEBSTER; OLIVER, 1990). In total, 136 TDR probes were installed to monitor soil water storage.

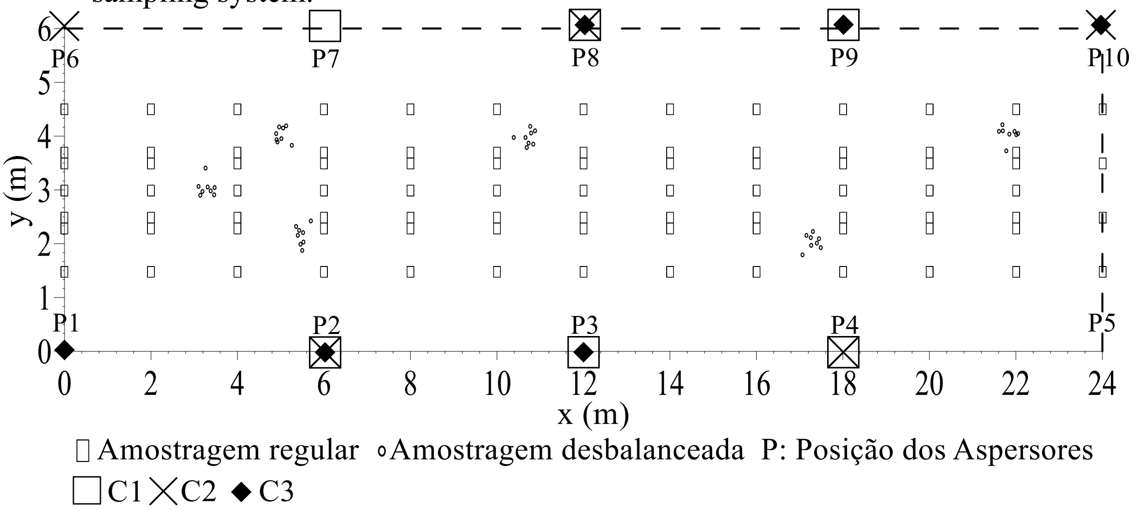
The irrigation system used was a conventional fixed sprinkler, consisting of a main line and two adjacent lateral lines spaced 6.0 m apart and with a total length of 24.0 m, where five riser pipes were allocated for the installation of sprinklers spaced 6.0 m apart. The sprinklers used were Fabrimar brand, model Eco A232, with 4.2 × 3.0 mm nozzle combinations installed at a height of one meter and subjected to a service pressure of 250 kPa at the time of irrigation, measured with the aid of a pressure gauge on the riser pipe.

Above the soil surface, next to each probe of the regular sampling system, a water collector with a nozzle diameter of 0.08 m was installed, supported by a metal rod, to collect the water applied to the surface of the area. The time to irrigate was defined on the basis of the readings of the dielectric constant of the medium (Ka) via the TDR technique. To convert the Ka readings to volume-based moisture (θ), the calibration equation ($\theta = 0.0137*Ka + 0.1341$) for the same soil employed by HARA *et al.* (2020) was used.

The wetting cycle consisted of measuring the stored soil water depth (H) at all sampling positions before the occurrence of the irrigation water depth (lirr), referred to as the preapplication moment ($_{A0}$), and subsequently collecting H data at various time points after the occurrence of lirr, referred to as Ai, with the i-th time point evaluated. Thus, when the soil moisture returned to levels close to the previous applied water depth, a new application was performed, enabling the evaluation of several soil wetting cycles. In all the scenarios, a lirr was applied with the aim of increasing the soil moisture to field capacity.

The data under study originate from the evaluation of three distinct soil water storage scenarios during the crop development period. These scenarios were created using different spacings; thus, sprinklers were arranged in the area to achieve water application with varying levels of uniformity, as shown in Figure 1.

Figure 1. Sketch of the experimental area with the position of the sprinklers arranged at 6.0 × 6.0 m spacing and the positions of the TDR probes for the regular and nested sampling system.



The first scenario (C1) consists of an average applied blade of 22.30 mm, with the sprinklers allocated in positions P2, 3, 4, 7, 8 and 9, as shown in Figure 1, providing a low-uniformity application. To evaluate scenarios with high application uniformity, two more irrigations were carried out, one with sprinklers operating at positions P2, 4, 6, 8 and 10, with an average blade of 30.08 mm characterizing the second scenario (C2), and one with an average blade of 30.07 mm and positions equal to P1, 2, 3, 8, 9 and 10, characterizing the third scenario (C3).

For all the scenarios, soil water storage was measured before irrigation and was repeated four times during soil drying until the average storage returned to levels close to the storage level before irrigation.

The data sets were subjected to descriptive and exploratory statistical analysis, as proposed by Gonçalves, Folegatti and Da Mata (2001), to verify the adherence of the frequency distribution to normality or the symmetry of the distribution of the data sets, as well as the presence of outliers. For the latter, the lower and upper limit criterion was adopted, according to Libardi *et al.* (1996).

After statistical analysis and confirming that the stochastic process of the random variable under study meets the hypothesis of at least intrinsic stationarity, we sought to describe the spatial dependence structure through variographic analyses based on the estimate of the semivariance function given by Equation 1:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(s_i) - Z(s_i + h)]^2 \qquad (1)$$

where γ(h) is the estimated semivariance; N(h) is the number of pairs of values of the variable Z, measured at points separated by distance h; and $Z(s_i)$ is the value of the variable Z at location s_i in space.

Since the different semivariograms obtained at the different time points were similar, it was possible to adopt an average scaled semivariogram, according to the methodology proposed by Hara *et al.* (2019). According to the authors, obtaining an average scaled semivariogram allows the detection of a central tendency and facilitates the interpretation of spatial continuity. Therefore, the average scaled semivariogram was calculated via equations 2 and 3:

$$\overline{\gamma(h)} = \sum_{i=1}^{(\Delta h)} \gamma^*(h) N(\Delta h)^{-1} \quad (2)$$

$$\bar{h} = \sum_{i=1}^{(\Delta h)} h N(\Delta h)^{-1} \quad (3)$$

where $\overline{\gamma(h)}$ represents the average scaled semivariance; $\gamma^*(h)$ represents the scaled semivariance; Δh represents the fixed distance interval of the cluster (0.2 m); $N(\Delta h)$ represents the number of values of the variable Z, existing in Δh; and $\bar{h}$ represents the average distance.

The experimental semivariograms were obtained via VARIOWIN software. The coefficients of the theoretical model were adjusted via the R statistical program and validated via the t test at 95% probability. To analyze the degree of spatial dependence of the variables under study, the classification of Cambardella *et al.* (1994) was used. The model adjusted to the mean semivariogram was used to perform kriging interpolation of storage values in nonsampled locations. For this purpose, Surfer 10 software was used.

5 RESULTS AND DISCUSSION

The data related to lirr are presented in Table 1. The high coefficient of variation presented in C1 indicates greater dispersion of values around the mean, consequently providing a lower CUC value (68.30%), indicating, therefore, irrigation with low application uniformity (MERRIAN; KELLER, 1978). For the other scenarios, the different spacings between sprinklers used provided uniform application of lirr within the evaluated limits, presenting a low CV value and high CUC (> 85%).

Table 1. Descriptive statistics of lirr values, in mm, for the three scenarios under study.

Water depth applied via irrigation (mm)							
Scenarios	Note:	Average	Median	CV (%)	Asymmetry	Kurtosis	CUC (%)
C1	87	22.38	24.89	38.06	-0.71	-0.60	68.30
C2	86	30.08	30.19	15.94	-0.11	0.04	86.76
C3	80	30.07	30.60	14.48	-0.59	0.18	88.05

The soil water storage values in the 0.20 m layer evaluated in the three scenarios and at different times throughout the soil drying process are presented in Table 2. Notably, for all the scenarios under study, the series referring to soil water storage reflected symmetrical distributions, adjusting to normality, a fact that can be proven by the values very close to the mean and median, as well as the values of the asymmetry and kurtosis coefficients close to zero.

Table 2. The soil water storage values, expressed in mm, were measured before irrigation (A_0) and after irrigation (A_i) over time.

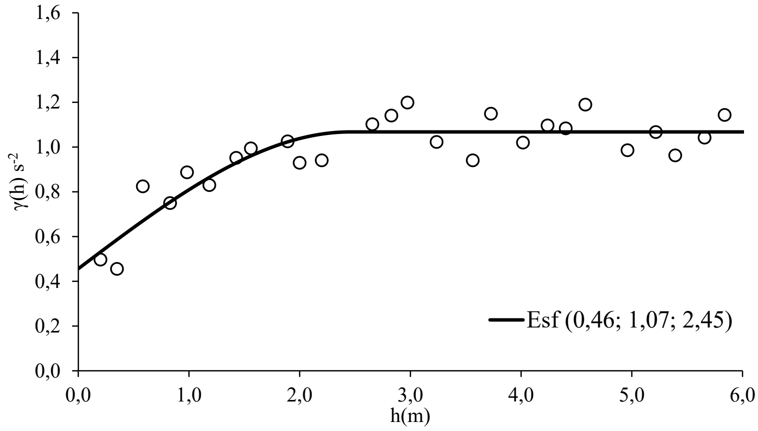
				Storage (mm)				
Scenarios		Note:	Average	Median	CV (%)	Asymmetry	Kurtosis	CUC (%)
C1	A_0	123	88.79	87.37	19.02	0.14	-0.19	84.83
	A_1	113	115.00	115.05	10,11	-0.52	-0.26	92.11
	A_2	114	107.84	108.88	11.72	-0.36	-0.41	90.47
	A_3	114	102.88	102.58	13.01	-0.19	-0.10	89.38
	A_4	119	86.28	86.55	14.74	-0.03	-0.03	88.42
C2	A_0	118	75.68	76.69	15,18	-0.45	0.17	88.15
	A_1	119	109.59	110.66	8.71	-0.27	-0.17	93.02
	A_2	119	94.80	92.85	10.73	-0.09	-0.18	90.74
	A_3	119	87.58	87.37	12.71	-0.18	0.37	90.10
	A_4	116	75.27	77.10	14.83	-0.46	0.29	88.41
C3	A_0	116	70.46	71.76	15.96	-0.37	-0.16	87.45
	A_1	119	105.90	105.46	10.38	-0.11	-0.35	91.67
	A_2	120	94.89	94.77	10.73	-0.12	0.32	91.45
	A_3	114	87.73	87.92	11.89	-0.22	0.15	90.57
	A_4	111	72.02	73.13	15.21	-0.39	-0.29	88.00

With respect to storage over time, the CV value decreased considerably after irrigation in all the scenarios and remained at lower levels even after the soil was drier on average (A_4) than before irrigation (A_0). For C1, even though the irrigation depth was considered to have low uniformity, it promoted greater uniformity within the soil because of the water dynamics in the soil profile, which were persistent over time. This greater uniformity can be explained by the gradual increase in CUC values after irrigation, which persisted throughout the soil drying process.

At time A_4, for all the scenarios, the soil returned to the moisture condition prior to irrigation (A_0), at which time the CV value, as well as the CUC value, returned to values close to time A_0. Although different studies have shown the importance of soil water redistribution in relation to the uniformity of applied water (REZENDE *et al.*, 1988; ROCHA *et al.*, 1999; RODRIGUES *et al.*, 2001; ZOCOLER *et al.*, 2013), they consider soil water storage to be constant. However, studies such as those carried out by Gonçalves, Folegatti and Vieira (1999b) and Torres *et al.* (2016) describe soil water storage as being variable in space. In this study, in addition to describing the spatial variability of soil water storage, it was possible to demonstrate the persistence of a storage pattern that was not influenced by crop action or by the uniformity of water application from sprinklers, corroborating the results of Hara *et al.* (2019) and Guimarães *et al.* (2010).

The average scaled experimental semivariogram for water storage (Figure 2) reveals the existence of a spatial dependence structure, which can be described by means of a spherical model for the three scenarios evaluated.

Figure 2. Average scaled experimental semivariogram for all soil water storage values before and after water application in the different scenarios evaluated and the adjusted spherical model.

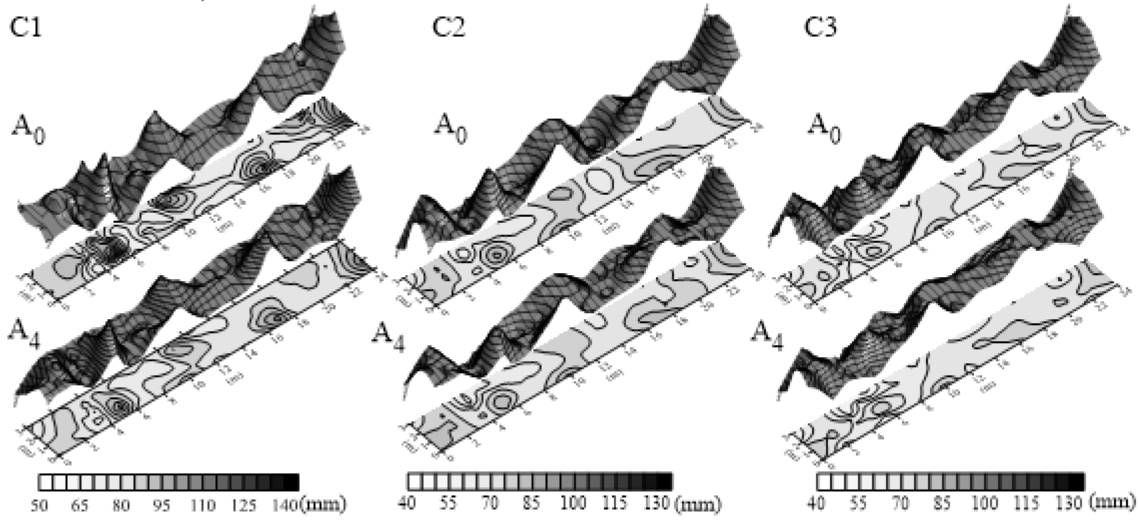


The model presents a nugget effect of 0.46, a plateau of 1.07, and a range of 2.45 m, which corresponds, according to Cambardella *et al.* (1994), to a moderate spatial dependence structure. The nugget effect value corresponds to 42% of the plateau; therefore, 58% of the total variation is due to the spatial dependence structure. According to Gonçalves, Folegatti, and Silva (1999a), a high nugget effect value is due to imperfections in the measurement process, in addition to the structural variation at distances smaller than the spacing adopted in the study.

The identification of similar patterns of spatial continuity that were described through a single semivariogram scaled by the sampling variance, for all scenarios even when they received water application with different levels of uniformity, corroborates the idea that the water application pattern has little interference in the spatial pattern of water storage in the soil, which depends, fundamentally, on its intrinsic characteristics (GONÇALVES *et al.*, 2010; GUIMARÃES *et al.*, 2010; HARA *et al.*, 2019).

The spatial distributions of soil water storage at times A0 and A4 for the different scenarios under study are presented in Figure 3. Note that, for all the scenarios, even with different CUC and water application patterns, both before irrigation and at time A4, when the soil moisture is close to that at A0, the value surfaces are similar. A comparison of these values revealed that the spatial distribution before irrigation was maintained after the drying process. This temporal persistence of the soil water storage pattern is consistent with the results of Gonçalves *et al.* (2010) for a dystrophic Red Nitosol with a clayey texture and Salvador *et al.* (2012) for a dystrophic Red–Yellow Latosol with a medium to sandy texture.

Figure 3. Spatial distributions of soil water storage values before irrigation A0 and at time A4, in mm, for the three scenarios studied.



6 CONCLUSION

For all the scenarios, soil water storage presented a moderate spatial dependence structure, which could be adjusted by a single average model, allowing its mapping via geostatistical techniques. Water input via irrigation with different spacings and uniformities did not affect the soil water storage pattern, which proved to be a characteristic that expresses intrinsic factors.

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