Revista Ciência Agronômica, v. 50, n. 2, p. 234-241, abr-jun, 2019
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Moisture in the soil profile with water applications using pulse drip irrigation[1]

Umidade no perfil do solo com aplicações de água por pulsos utilizando gotejamento

André Maller[2]*, Roberto Rezende[2], Paulo Sérgio Lourenço de Freitas[2], Cassio Castro Seron[2] and Tiago Luan Hachmann[2]

ABSTRACT - The wet bulb, as a result of local application of irrigation water, is the soil volume that presents higher water content in relation to the surrounding soil. Due to increased moisture in the soil, successive irrigation events tend to form bigger wet bulbs and superficial water accumulation area (AWSS). The objective was to verify the distribution of water in the soil profile, with intermittent application of water, considering the hypothesis that antecedent soil water content modifies the wet bulb characteristics after water pulse application, and to evaluate the effect of increasing AWSS on the lateral dimensions of the bulb. The water applications were performed using 1, 2 and 4 pulses in the flows of 4 and 8 L h^{-1}, totalizing six treatments, which were carried out in four replications for each treatment. The evaluations of AWSS were performed with the continuous application of water at the mentioned flow rates. The results indicate increasing AWSS does not affect the wet bulb, differences in the distribution of soil water are visible only in the first moments after last pulse application. It was concluded water tends to distribute in the soil regardless of the amount of irrigation pulses and pulse irrigation tends to result in similar distribution of moisture inside the wet bulb in relation to continuous irrigation.

Key words: Wet bulb. Soil water distribution. Antecedent soil water content. Pulse irrigation.

RESUMO - O bulbo molhado, como resultado da aplicação pontual de água de irrigação, é o volume de solo que tem maior umidade em relação à umidade inicial. Devido ao incremento de umidade no solo, sucessivos eventos de irrigação tendem a formar bulbos molhados e área de acúmulo superficial de água (AASA) maiores. Portanto, objetivou-se avaliar a distribuição de água no perfil do solo, com a aplicação intermitente de água, por irrigação por gotejamento, e o aumento da AASA nas dimensões laterais do bulbo úmido. Para isso, foram realizadas aplicações de água por meio de 1, 2 e 4 pulsos nas vazões 4 e 8 L h^{-1}, totalizando seis tratamentos, em que foram realizadas quatro repetições para cada tratamento. As avaliações da AASA foram realizadas com a aplicação de água de forma contínua nas vazões citadas. Os resultados indicam que o incremento da AWSS não afeta o bulbo molhado e que as diferenças na distribuição de umidade em seu interior são visíveis apenas nos primeiros momentos após a aplicação do último pulso porque a água tende a se redistribuir no solo independente da quantidade de pulsos aplicada e que a irrigação pulsante tende a resultar em distribuição de água no solo similar à irrigação contínua.

Palavras-chave: Irrigação pulsante. Distribuição de água no perfil. Parcelamento da lâmina de água.

DOI: 10.5935/1806-6690.20190027
*Author for correspondence
Received for publication in 08/10/2016; approved in 12/06/2018
[1]Parte da Dissertação de Doutorado do primeiro autor, apoio financeiro concedido pela CAPES
[2]Departamento de Agronomia, Universidade Estadual de Maringá/UEM, Maringá-PR, Brasil, anmaller@hotmail.com (ORCID ID 0000-0002-3312-9404), rrezende@uem.br (ORCID ID 0000-0002-6213-1845), pslfreitas@uem.br (ORCID ID 0000-0001-6663-2797), cassioseron@msn.com (ORCID ID 0000-0003-4289-931X), tiagohach@gmail.com (ORCID ID 0000-0002-1298-5682)

INTRODUCTION

Pulse drip irrigation is the technique in which the application of the required volume of each scheduled irrigation is divided into several aplications. Each aplication is followed by a resting period of the system (KARMELI; PERI, 1974).

The application of water with greater intensity than the soil infiltration capacity results in accumulation of water on the surface, called saturated disc (SOUZA; FOLEGATTI, 2010), which is a very common phenomenon in drip irrigation. The shape of the superficial water accumulation area is related to the roughness of soil surface. For this reason, to characterize the accumulation area as disc shape is a cumbersome task. Due to the limitation of the term, the saturated disc will be denominated accumulation of water on soil surface (AWSS).

Gonçalves *et al*. (2014) concluded that the wet bulb formed through irrigation with the emitter above the surface of a sandy soil presents greater lateral advancing of the wetting front and smaller depth in relation to the bulb formed with the emitter located below the soil surface. This result may be related to the AWSS. This area tends to be greater in successive irrigation events as well as the dimensions of the wet bulb (SOUZA; FOLEGATTI, 2010).

Effects of pulse irrigation on soil moisture are listed in the literature, such as increase in the ratio between the stored volume of water in the rhizosphere and the applied volume (BAKEER *et al*., 2009) and greater volume of soil with moisture equal or superior to the field capacity (EID; BAKRY; TAHA, 2013). However, other authors claim that differences on soil water distribution between pulse and continuous irrigation tend to disappear over time (ELMALOGLOU; DIAMANTOPOULOS, 2007; SKAGGS; TROUT; ROTHFUSS, 2010).

Considering the presented arguments, the objectives of this study were to verify the relation between the AWSS originated through different drip flows and the horizontal expansion of the wet bulb and to verify if the pulse irrigation results in alteration of the characteristics of the wet bulb in relation to continuous irrigation.

MATERIAL AND METHODS

The experiment was conducted in the Irrigation Technical Center (CTI) of the Agronomy Department at the State University of Maringá (UEM), in Maringá, PR, 23°25' S and 51°57' W and 542 m above sea level, between the months of 08/2014 and 02/2015.

The experimental area was composed of a 1.0 m long, 0.7 m wide and 0.7 m deep container, filled with a layer of 0.07 m of gravel at the bottom and 0.03 m of sand in the middle part. Finally, soil was added from the superficial horizon, sieved through 2 mm mesh, up to the edge. The soil used was classified as Nitisol (WORLD REFERENCE BASE FOR SOIL RESOURCES, 2014) with sand, silt and clay content of 132.6; 120.6 and 746.8 g kg^{-1}, respectively. Six undisturbed samples of the experimental area were collected to determine moisture at the potentials of -6 and -10 kPa using tension table and 12 undisturbed samples had the moisture determined at the potentials of Richards chamber method (MANUAL, 2011). The Van Genutchen model was used to adjust the retention curve.

The saturated hydraulic conductivity (Ks) was obtained via the Simplified Falling-Head Technique (BAGARELLO; IOVINO; ELRICK, 2004). The tube used in the test was 4.9 cm in diameter. It was inserted 3 cm into the soil surface and filled with 200 mL of water for testing. The Ks values of the repetitions performed were 13.1; 20,5; 23,9 and 33,7 mm h^{-1}.

In order to accommodate the soil particles throughout the container volume, water was added through a pipe installed at the bottom, followed by drainage. The procedure was necessary to increase the accuracy of the soil moisture estimate through the dielectric constant measures (Ka), since the heterogeneity of soil density reduces the accuracy of such estimates (GONÇALVES *et al.*, 2011). The bulk density of soil after accommodation of soil particles was 1,05 kg dm^{-3}. The experiment was conducted in a covered environment and protected from direct sunlight.

The AWSS was photographed using a digital camera with resolution of 4 megapixel attached to a support 0.73 m high. The digital image processing consisted of distinguishing the surface which presented water accumulation through QUANT and Adobe Photoshop programs. Then, the AWSS was calculated in relation to a default area of a white paper measuring 0.06 x 0.08 m. The AWSS and the default area were photographed simultaneously. Four replications were performed for each drip flow (4 and 8 L h^{-1}).

Moisture estimate was carried out using a Time Domain Reflectometer equipment (TDR) Trase System model. 30 probes were installed, spaced 0.08 and 0.06 m apart horizontally and vertically, respectively. The drip points were located on the horizontal coordinates 0 and 40 cm, while the probes were installed at 4, 10, 16, 22 and 28 cm depths. Readings were performed using 30 channels multiplexer, capable of performing three readings per minute. The TDR technique is appropriated to estimation of wet bulb dimensions (BUFON *et al*., 2012).

The probes were constructed using BNC connectors, two meters coaxial cable and resin for lamination to form a body of 5 x 5 x 2.5 cm, in which a 4.7 picofarad capacitor was completely immersed and two stainless steel rods were partially immerse. The rods had 2.6 mm diameter and 0.20 m of exposed length which can be inserted in the soil. The probe components were joined by electronic solder 60/40.

The equation that relates the apparent dielectric constant of the soil (Ka) and soil moisture volumetric basis (θ) was adjusted by means of data obtained with cylindrical containers of 0.25 m high, filled with air-dried soil of defined density and with two probes inserted. The container was saturated from the bottom for 24 hour to assure maximum expulsion of air from within the pores. The Ka value and soil moisture gravimetric basis were measured during the drying of the soil, originating data pairs for the adjustment of the equation (Eq. 1). Model adjustment and test were performed with 1187 and 505 data pairs respectively. The coefficient of determination for model adjustment was equal to 0.82.

$$\theta = 0{,}0000442\,Ka^3 + 0{,}00273\,ka^2 - 0{,}0411\,Ka + 0{,}4774 \quad (1)$$

Which are θ is the soil moisture ($m^3\ m^{-3}$) and K is the apparent dielectric constant of the soil. Water applications were performed with a 24 hour interval in order to ensure complete water distribution in the profile (SKAGGS; TROUT; ROTHFUSS, 2010). For all applications, the total applied volume and the interval between readings were equal to 2.67 L and 30 min respectively.

The treatments were the result of the combination of emitter flow (4 and 8 L h^{-1}) and number of pulses (1, 2 and 4) totaling six treatments. The treatment related to the flow of 4 L h^{-1} with 1, 2, and 4 pulses are represented by 1P4, 2P4 and 4P4, respectively, and the treatments related to the flow of 8 L h^{-1} with 1, 2, and 4 pulses are represented by 1P8, 2P8 and 4P8, respectively. Drippers were placed at distances of soil surface of 0.00 and 0.40 m. Reading intervals counted from the start of dripping were standardized at 60 and 150 min. Additionally, Ka measurements were performed for the treatments 1P8 and 2P8 at 30 min. The interval between the end of the last pulse and the reading was not the same for all treatments, as shown in Figure 1.

In order to eliminate systematic errors of moisture estimates, moisture increments (INCθt) were considered in relation to the estimated values of moisture prior to the application, according to Eq. 2:

$$INC\theta_t = \theta_t - \theta_a \quad (2)$$

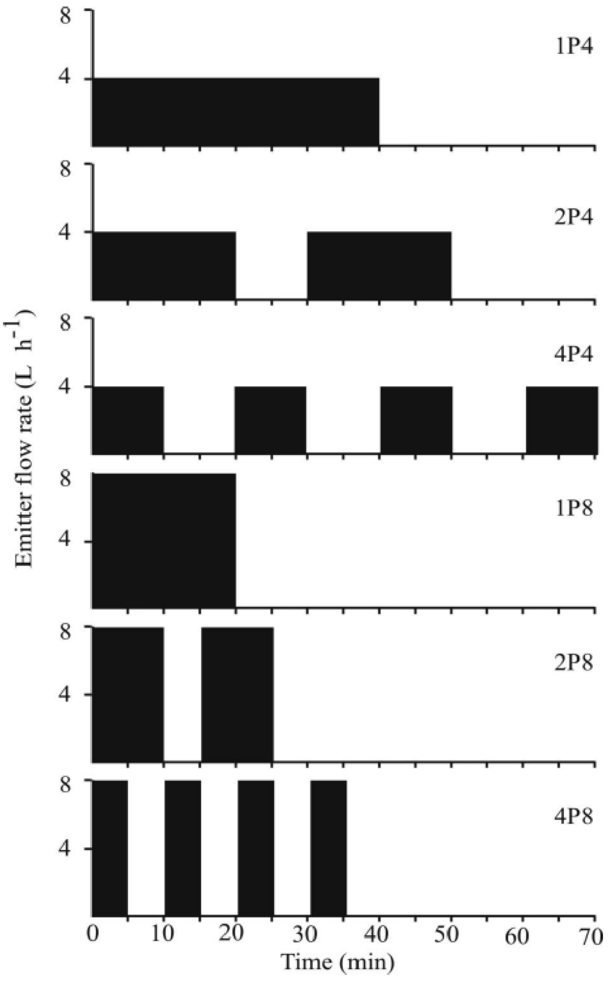
Which are θt is the estimated moisture at the t moment after the start of the application ($m^3\ m^{-3}$) and θa is the moisture before the application ($m^3\ m^{-3}$). Variogram analysis of the spatial distributions of INCθt in the soil profile at 30, 60 and 150 min after application were performed, through which was observed that the spherical model was the best in describing the spatial continuity of INCθt. The semivariogram is an appropriate tool for the analysis of the spatial distribution of water in the profile (GONÇALVES; FOLEGATTI; SILVA, 1999).

The spatial correlation can be confirmed by the crossed semivariogram. Its mathematical model can be expressed by Eq. 3:

$$Cross-\gamma(h)_{12} = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[Z_1(si)-Z_1(si+h)\right]\left[Z_2(si)-Z_2(si+h)\right] \quad (3)$$

Which are Cross-$\gamma(h)_{12}$ is the estimated cross semivariance of Z_1 and Z_2 variables; N(h) is the number of pairs of values

Figure 1 - Treatments employed, their emitter flow rate and interval between pulses



of Z_1 and Z_2 variables measured at locations separated by the distance h, $Z_1(si)$ is the value of the variable Z_1 at the si location and $Z_2(si)$ is the value of the variable Z_2 at the si location.

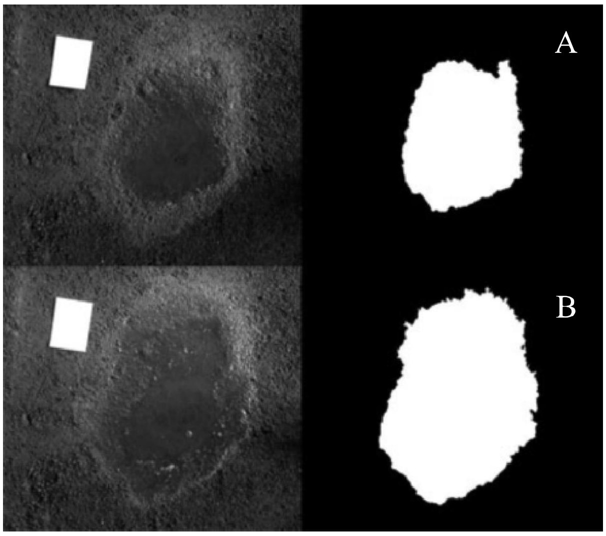
Eq. 4 was used by Gonçalves, Folegatti and Silva (1999) to perform the scaling of the crossed semivariograms and can be expressed by:

$$Cross^{*}\text{-}\gamma(h)_{12} = Cross\text{-}\gamma(h)_{12} / |cov(Z_1 Z_2)| \quad (4)$$

Which are Cross*-$\gamma(h)_{12}$ is the estimated scaled cross semivariance of the Z_1 and Z_2 variables; and $|cov(Z_1;Z_2)|$ - the covariance module of Z1 and Z2 variables.

The model coefficients were used in the interpolation of the values through kriging and to obtain the INCθt distribution maps. The geostatistical analyzes were performed by the GS + for Windows software version 5.0.3 and Surfer version 10.

Figure 2 - Surface water accumulation area resulting from the flow rates of 4 (A) and 8 h L^{-1} (B)



RESULTS AND DISCUSSION

The Van Genutchen model with the adjusted parameters can be expressed by:

$$\theta = 0{,}107 + (0{,}581 - 0{,}107)/[1 + (0{,}2441\Psi^{1{,}0881})]^{0{,}0805} \quad (5)$$

Wich are θ is the soil moisture ($m^3\ m^{-3}$) and Ψ is the soil water potential module ((hPa). The average Ks value obtained was 22.8 mm h^{-1}. This value can be considered high according to Bernardo, Soares and Mantovani (2006) and can be related to the arrangement of clay particles in small granules. The soil structure in the experimental area was disturbed and the accommodation of particles was not enough to reestablish the soil structure. As a result, the granular structure of the soil was similar to sandy soil in what concerns to water infiltration (ALVES SOBRINHO *et al*., 2003). AWSS (Figure 2) tends to show constant values with the increase of the application period. It stabilizes at higher values in high flow drippers and tends to disappear quickly with the end of the application. The average AWSS for the flow rates of 4 and 8 L h^{-1} were equal to 0.2114 and 0.4631 m^2 respectively. The treatments were significantly different ($F=114$, $p<0.001$).

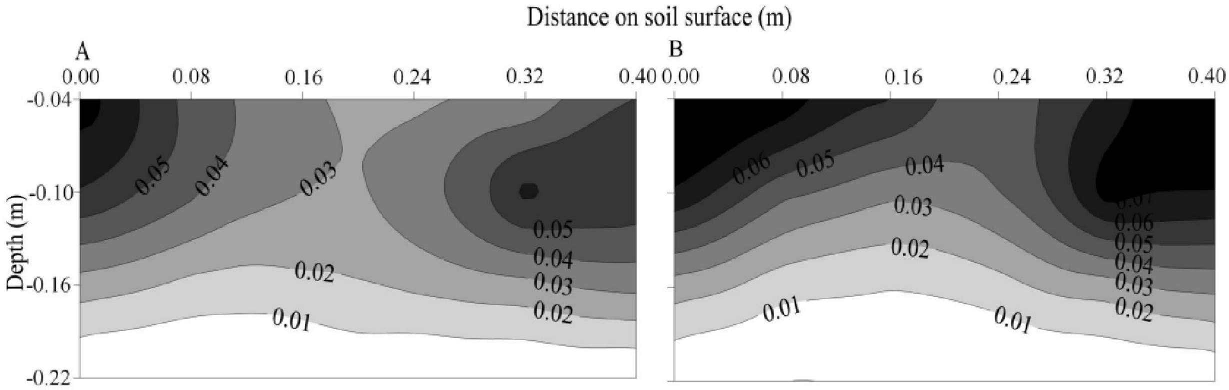
The AWSS formation is apparently related to the increase of the lateral dimensions of the bulb. Gonçalves *et al*. (2014) conclude that the wet bulb formed through irrigation using emitter above the surface, resulting in AWSS formation, presents greater horizontal advance of the wetting front in relation to subsurface irrigation, which does not result in AWSS formation. The present results do not corroborate the author, as it is possible to observe that the water distribution of the treatments 1P8 and 1P4 150 min after the start of the application were practically equal and presented smaller depth in relation to the bulb formed with the emitter located below the soil surface. It is noteworthy that the surface drip results in AWSS formation, while subsurface drip does not. According to Gonçalves *et al*. (2014), deep percolation losses with subsurface drip are intensified with the increase of the dripper flow.

The pulse application resulted in higher moisture increment in the superficial layer 30 minutes after the start of the irrigation, (Figure 3), although the same volume of water for the same time interval was applied. The higher moisture increase in the superficial layer was expected, since the readings taken 30 minutes after the start of the irrigation through 2 pulses were taken immediately after the end of the application of the last pulse (Figure 1C), while the readings taken 30 min after the start of the irrigation through 1 pulse were taken 10 min after the end of the application. During this period, water was redistributed in the profile resulting in decrease of INCθ values in the region between emitters (Figure 3A).

The distribution of water in the soil profile for different treatments, after a standard time counted from the start of the water application is presented in Figure 4. It is noted that the contours of the wet bulb were more defined in the application through 4 pulses, followed by application through 2 and 1 pulse, even though the reading time was 60 minutes after the start of the application to all situations. However, it is noteworthy that the interval between the end of the last pulse and the reading was not the same for all treatments (Figures 3B and 4A).

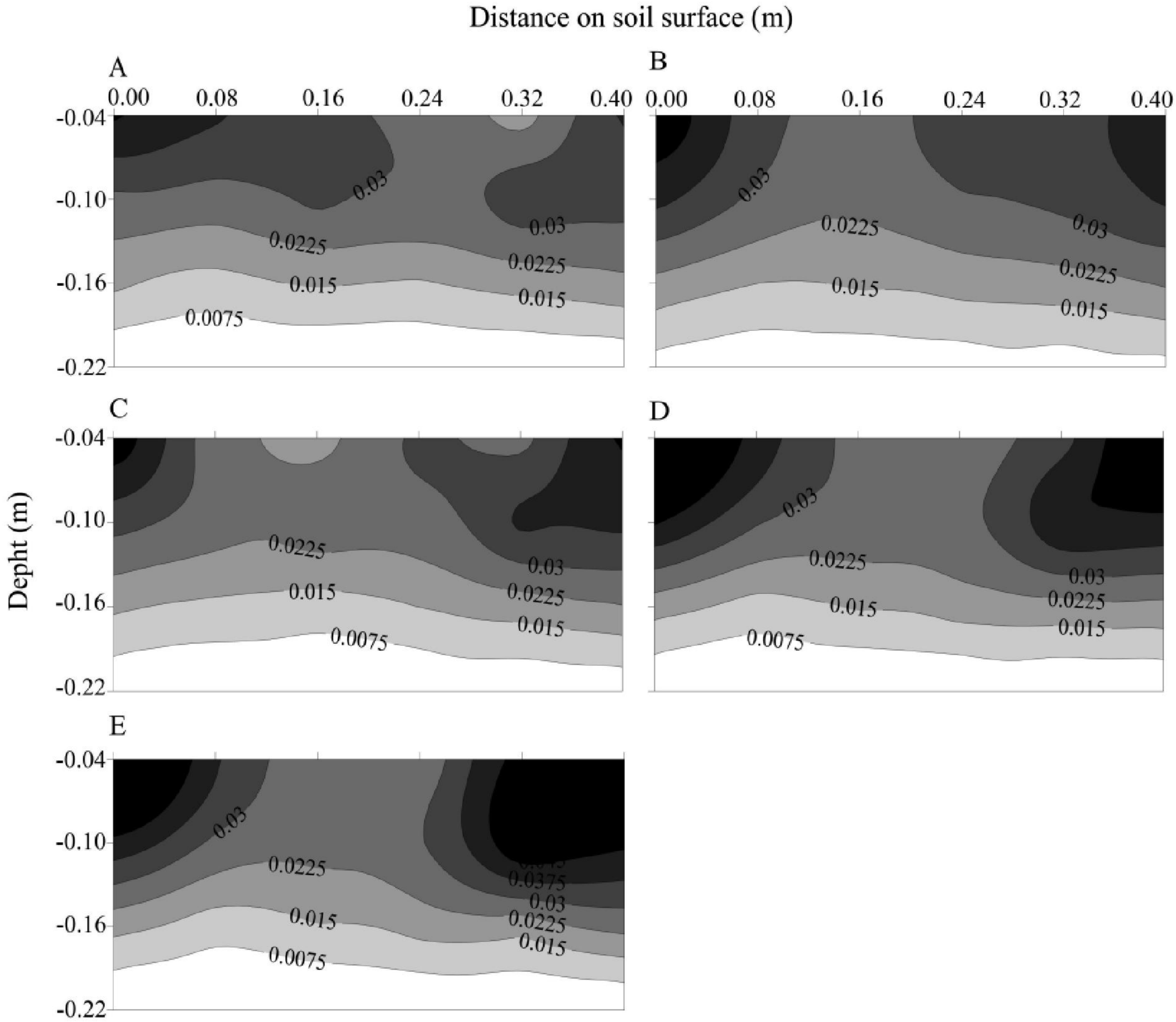
The formation of the wetted strip occurred at 60 min after application, regardless of the dripper flow or the

Figure 3 - Moisture increment in the profile regarding 1P8 and 2P8 treatments, 30 min after the start of the application (A and B respectively)*



* - Drippers were placed at soil surface distances of 0.00 and 0.40 m

Figure 4 - Moisture increment in the profile regarding 1P8, 1P4, 2P8, 2P4 and 4P8 treatments, 60 min after the start of the application (A, B, C, D and E respectively)*



* - Drippers were placed at soil surface distances of 0.00 and 0.40 m

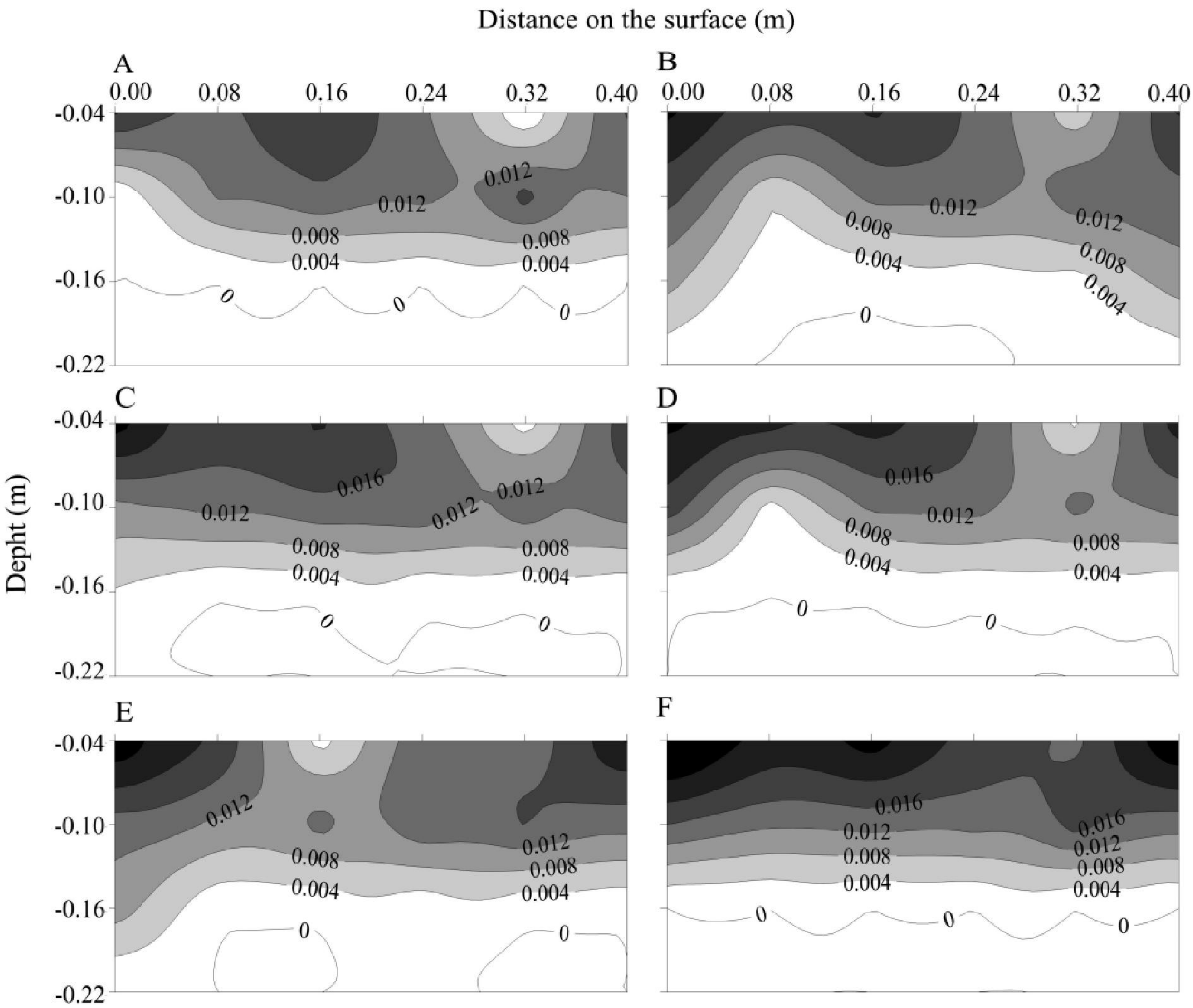
number of pulses used. Figure 4 shows that the increases in moisture occurred practically at the same depths in all applications. It is probable that the water distribution in the soil is more related to the soil hydraulic conductivity and the previous moisture than to the water application characteristics (SKAGGS; TROUT; ROTHFUSS, 2010).

The analysis of the two-dimensional spatial distribution of moisture increment 60 min after application (Figure 4) shows that the concentration of moisture increase was more related to the period after the end of the application than the period after the beginning of the application. The intervals between the end of the last pulse and reading were 10, 30 and 40 min for the treatments 4P8, 2P8 and 1P8, respectively. It is noted higher moisture in a smaller area of the profile under the dripping point 10 minutes after the end of the last pulse.

Figure 5 shows the spatial distribution of the moisture increment 150 min after the start of the application. It is observed that the water distribution was relatively homogeneous in all treatments. This result corroborates that of Skaggs, Trout and Rothfuss (2010), which state that the water redistribution process is more associated with the soil characteristics than the characteristics of the water application. It is also possible to conclude that moisture tends to redistribute in the profile over time.

The present results allow inferring that the effects of pulse irrigation in water distribution are ephemeral. Figure 5 shows that after 150 minutes from the start of the application, the distribution of moisture increment in the profile tended to be similar, regardless of the amount of pulses applied, the AWSS characteristics and the flow of the drippers used. This result corroborates Elmaloglou and

Figure 5 - Moisture increment in profile regarding the treatments 1P8, 1P4, 2P8, 2P4, 4P8 and 4P4 150 minutes after the start of the application (A, B, C, D and E respectively)*



* - Drippers were placed at soil surface distances of 0.00 and 0.40 m

Diamantopoulos (2007), which state that the difference in percolation comparing pulse and continuous drip tends to be zero with the redistribution of water in the soil.

Phogat *et al.* (2012) concluded that pulse irrigation and emitter flow have discrete effects on the distribution of water in sandy soils. The results from the present study corroborate this conclusion, despite being generated in clayey soil.

Studies about wet bulb dimensions were performed considering the soil hydraulic conductivity with different textures (HAO *et al*., 2007). It was concluded that for the same soil and application intensity, the maximum depth of the bulb is related to the total volume applied. This conclusion corroborates the results of the present work.

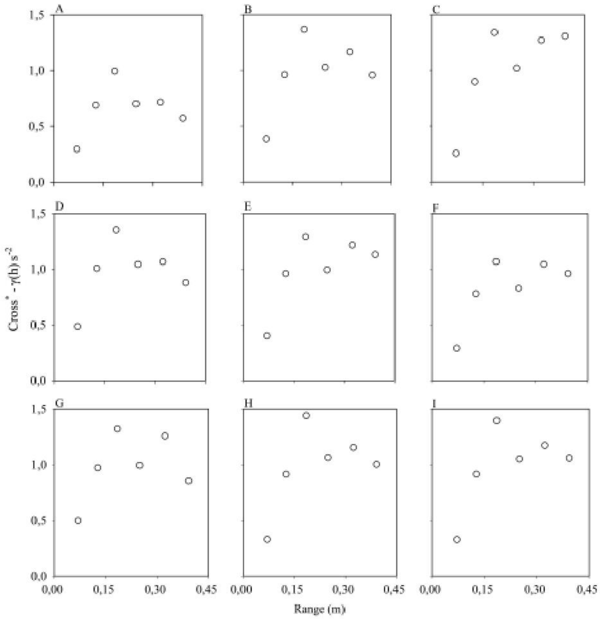
The hydraulic characteristics of the soil influence in a relevant way the advancing of the wetting front in depth (ELMALOGLOU; DIAMANTOPOULOS, 2008), which is closely related to the depth of the bulb. The same authors state that pulse irrigation is associated with a small reduction of the water percolation. However, results in this work does not corroborate this statement. Moreover, the moisture previous to the irrigation is a much more important factor in deep percolation losses than pulse irrigation (PHOGAT *et al*., 2013).

The results suggest that there is spatial correlation between the treatments regarding the same number of pulses (Figures 6A, 6B and 6C) and the same flow (Figures 6D, 6E and 6F for the flow of 8 L h^{-1} and Figures 6G, 6H and 6I for the flow of 4 L h^{-1}), which reinforces the conclusion that the moisture distribution in the profile 150 minutes after the beginning of the irrigation tends to be similar, regardless of the flow and the number of pulses used.

Elmaloglou and Diamantopoulos (2009) state that water moves downwards more quickly in pulse irrigation than continuous irrigation, resulting in deeper advance at the end of irrigation. However, results in this work allow to conclude that the wet bulb depth tends to be similar after soil water redistribution in pulse and continuous irrigation.

Irrigation with wastewater water is associated with problems of clogging of emitters due to the high content of suspended solids (ABDELRAOUF *et al.*, 2012). Irrigation of wastewater water by pulses can reduce clogging problems, resulting in increased irrigation efficiency. However, it is questionable to use pulse irrigation in conditions which emitters clogging is not a limitation (ELNESR *et al.*, 2015). On the other hand, the increase in the frequency of irrigation events associated with the reduction of the applied water depth is a necessity for irrigation management in sandy soils, since this strategy tends to reduce losses due to deep percolation. In this case, pulse irrigation is recommended (MORILLO *et al*., 2015).

Figure 6 - Cross semivariograms of the water distribution in the profile regarding the treatments 1P4 and 1P8, 2P4 and 2P8, 4P4 and 4P8, 1P8 and 2P8, 1P8 and 4P8, 2P8 and 4P8, 1P4 and 2P4, 1P4 and 4P4 and 2P4 and 4P4 (A, B C, D, E, F, G, H and I respectively), at 150 minutes after the start of the irrigation



The present study shows evidences that, although the application intensity is variable in time, the depth of the wet bulb is constant for the same applied volume in the condition where the soil physical properties are homogeneous in the profile.

CONCLUSIONS

1. The greater emitter flow rate, the greater the AWSS;
2. The effects of AWSS for water distribution in the profile are ephemeral in a homogeneous soil;
3. The pulse and continuous irrigation results in similar soil water distribution pattern after stabilization;
4. Before stabilization, the water distribution pattern in pulse irrigation is related to the time after last pulse application.

REFERENCES

ABDELRAOUF, R. E. *et al*. Effect of pulse irrigation on clogging emitters, application efficiency and water productivity of potato crop under organic agriculture conditions. **Australian Journal of Basic and Applied Sciences**, v. 6, n. 5, p. 807-816, 2012.

ALVES SOBRINHO, T. *et al*. Infiltração de água no solo em sistemas de plantio direto e convencional. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 7, n. 2, p. 191-196, 2003.

BAGARELLO, V.; IOVINO, M.; ELRICK, D. A simplified falling-head technique for rapid determination of field-saturated hydraulic conductivity. **Soil Science Society of America Journal**, v. 68, p. 66-73, 2004.

BAKEER, G. A. A. *et al*. Effect of pulse drip irrigation on yield and water use efficiency of potato crop under organic agriculture in sandy soils. **Misr Journal of Agricultural Engineering**, v. 26, n. 2, p. 736-765, 2009.

BERNARDO, S.; SOARES, A. A.; MANTOVANI, E. C. Manual de Irrigação. 8ed.Viçosa: UFV, 2006. 625p.

BUFON, V. B. *et al*. Soil water content on drip irrigated cotton: comparison of measured and simulated values obtained with the Hydrus 2-D model. **Irrigation Science**, v. 30, n. 4, p. 259-273, 2012.

EID, A. R.; BAKRY, B. A.; TAHA, M. H. Effect of pulse drip irrigation and mulching systems on yield, quality traits and irrigation water use efficiency of soybean under sandy soil conditions. **Agricultural Sciences**, v. 4, n. 5, p. 249-261, 2013.

ELMALOGLOU, S.; DIAMANTOPOULOS, E. Effects of hysteresis on redistribution of soil moisture and deep percolation at continuous and pulse drip irrigation. **Agricultural Water Management**, v. 96, n. 3, p. 533-538, 2009.

ELMALOGLOU, S.; DIAMANTOPOULOS, E. The effect of intermittent water application by surface point sources on the soil moisture dynamics and on deep percolation under the root zone. **Computers and Electronics in Agriculture**, v. 62, n. 2, p. 266-275, 2008.

ELMALOGLOU, S.; DIAMANTOPOULOS, E. Wetting front advance patterns and water losses by deep percolation under the root zone as influenced by pulsed drip irrigation. **Agricultural Water Management**, v. 90, n. 1/2, p. 160-163, 2007.

ELNESR, M. N. *et al*. Evaluating the effect of three water management techniques on tomato crop. **Plos One**, v. 10, n. 6, p. 1-17, 2015.

GONÇALVES, A. C. A. *et al*. Distribution of water in sandy soil applied by drip. **Engenharia Agrícola**, v. 34, n. 6, p. 1175-1185, 2014.

GONÇALVES, A. C. A. *et al*. Influência da densidade do solo na estimativa da umidade em um Nitossolo Vermelho Distroférrico por meio da técnica de TDR. **Revista Brasileira de Ciência do Solo**, v. 35, n. 5, p. 1551-1559, 2011.

GONÇALVES, A. C. A.; FOLEGATTI, M. V.; SILVA, A. P. Estabilidade temporal da distribuição espacial da umidade do solo em área irrigada por pivô central. **Revista Brasileira de Ciência do Solo**, v. 23, p. 155-164, 1999.

HAO, A. *et al*. Estimation of wet bulb formation in various soil during drip irrigation. **Journal of the Aculty of Agriculture**, v. 52, n. 1, p. 187-193, 2007.

KARMELI, D.; PERI, G. Basic principles of pulse irrigation. Journal of the Irrigation and Drainage Division, v. 100, n. 3, p. 309-319, 1974.

MANUAL de métodos de análise de solos. Rio de Janeiro: **Embrapa solos**, 2011. 230 p. il. (Documentos, 132).

MORILLO, J. G. *et al*. Toward precision irrigation for intensive strawberry cultivation. **Agricultural Water Management**, v. 151, p. 43-51, 2015.

PHOGAT, V. *et al*. Modelling soil water and salt dynamics under pulsed and continuous surface drip irrigation of almond and implications of system design. **Irrigation Science**, v. 30, n. 4, p. 315-333, 2012.

PHOGAT, V. *et al*. Evaluation of soil plant system response to pulsed drip irrigation of an almond tree under sustained stress conditions. **Agricultural Water Management**, v. 118, p. 1-11, 2013.

SKAGGS, T. H.; TROUT, T. J.; ROTHFUSS, Y. Drip irrigation water distribution patterns: effects of emitter rate, pulsing, and antecedent water. **Soil Science Society of America Journal**, v. 74, n. 6, p. 1886-1896, 2010.

SOUZA, C. F.; FOLEGATTI, M. V. Spatial and temporal characterization of water and solute distribution patterns. **Scientia Agricola**, v. 67, n. 1, p. 9-15, 2010.

WORLD REFERENCE BASE FOR SOIL RESOURCES. **WRB**: a framework for international classification, correlation and communication. Rome: IUSS: ISRIC: FAO, 2014. (World Soil Resources Reports, 106).