Spatial variation in soil moisture with subsurface drip irrigation in cane sugar

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The sugarcane agroecosystem has been the focus of much research. Mainly, because the sugarcane in Brazil has great economic importance and land occupancy. Prominent among this research is water replacement in the soil, which can be monitored by tensiometers. Therefore, this study aimed to monitor the matric potential at different positions in the soil to check the influence of the depth and horizontal distance from the tensiometer relative to the dripline in evaluating soil moisture in Dystrophic Red Latosol cultivated with sugarcane under subsurface drip irrigation. The experiment was conducted in the experimental area of the Federal Institute of Goias (IF Goiano), Campus Rio Verde, GO. The planting of sugar cane occurred in a double row, and the dripline was buried 0.20 m deep under the surface of the soil between the crop rows. The soil matric potential was recorded at four depths (0.20; 0.40; 0.60 and 0.80 m of the soil surface) and four horizontal distances from the dripline (0.15; 0.30; 0.45 and 0.60 m). The values of soil matric potential were evaluated through mathematical regressions and compared to each other using the homogeneity test for linear models. The depth of monitoring and the horizontal distance between the dripline and the tensiometric rods had strong and weak influences, respectively, in the soil’s matric potential. The highest values of soil matric potential were observed in the deeper layers of the soil.

Key words: Matric potential, wetted bulb, water replacement, dystrophic red latosol, Saccharum officinarum L.

INTRODUCTION

Brazil is the largest producer of sugar and alcohol in the world (MAPA, 2013). Thus, the sugarcane agroecosystem has been the focus of much research by virtue of its great economic importance and land occupancy (Barros et al., 2010). Mainly, because the sugarcane in Brazil generates approximately 25 billion dollars per year, due with the production and sale of sugar and ethanol. Sugarcane is a crop with a high degree of technology applied to its production system (Dalri and Cruz, 2008). Among the technologies applied to the production of sugarcane, soil water replacement can be highlighted. Water replacement is water of...
irrigation applied to soil, mainly for replace the amount of water lost by evapotranspiration, that is, the sum of evaporation and plant transpiration. This practice is of great benefit to the crop, because it provides for better growth of plants, increased productivity and improved quality in the product (Porto et al., 2014). Water replacement in the soil by subsurface drip irrigation has been notable for presenting numerous advantages, such as reduced water evaporation, reduced mechanical damage to the system, less interference with cultural treatments, improved efficiency of fertilizer application dissolved in water for irrigation (fertigation) and increased canebrake longevity (Andrade Júnior et al., 2012).

Drip irrigation is performed with a high frequency of water application to maintain the soil water content at field capacity for appropriate root proliferation (Souza and Folegatti, 2010). Therefore, due to the low water volume applied to soil, the accuracy in the frequency of applications is essential for correct water replacement, making it a necessity to obtain data referencing soil water content. To obtain data on soil water content it is necessary to monitor the energy state of soil water. Several devices are used, to access the energy state of soil water in particular tensiometers, which are instruments that measure the tension under which water is retained by pore spaces in the soil with different diameters (macro and micropores) due to capillarity and adsorption phenomena at the particles’ surfaces, called the conjunction matric potential (Bezerra et al., 2012).

Tensiometers used to monitor soil water potential must be placed at strategic points for correct monitoring of soil water potential. Martins (2009) noted that there have not been many studies about the distances between the points of measurement in the soil, with the actual distances used typically ranging from 0.20 to 0.40 m (Cintra et al., 2000; Hutchinson and Bond, 2001). Tensiometers located at various depths and distances may indicate the actual size of the wet bulb, yielding more precise information about soil water conditions.

In this sense, the aim of this study was to monitor the matric potential at different points on the ground to assess the influence of the depth and horizontal distance from the tensiometer relative to the dripline in the management of soil moisture in Dystrophic Red Latosol cultivated with sugarcane under subsurface drip irrigation. Thus, it will be possible to determine the soil moisture afforded by the application of water in the soil near the dripline.

**MATERIALS AND METHODS**

The experiment was performed in the experimental area of the Federal Institute of Goiás, campus Rio Verde, Goiás State, Brazil, 17°48'28"S and 50°53'57"W, mean altitude 720 m. The climate is classified according to Köppen (CastroNeto, 1982) as Aw (tropical), with rain in the months of October to May and drought from June to September. The average annual temperature is 23°C and precipitation ranges from 1500 to 1800 mm annually. Table 1 presents the meteorological data and of the culture during the study period. The soil is Dystrophic Red Latosol. Latosols are tropical mineral soils, very weathered and small reserves of soil nutrients for plants. These are deep soils with over 2 m depth, B-horizons very thick (greater than 50 cm) with sequence horizons A, B and C little differed. Table 2 presents the physical-hydro characteristics of the soil in the experimental area.

The initial preparation of the ground consisted of prior disk ing to remove the existing vegetation, mechanical distribution of limestone at a dose of 2.0 t ha⁻¹ and subsequent disk ing in order to incorporate the limestone at 0 to 20 cm depth and break up the clods of soil. Finally, it was made one ground leveling to build the planting furrows. Subsoiling was used, with subsequent removal of soil, raising the planting bed.

The planting of the sugarcane, cultivar RB85-5453, occurred on March 15, 2011, performed in a double-row (W-shaped), 8 m long, with 1.80 m spacing between the double rows. The distance between the crops in the double row was 0.40 m, with a total area of 35.2 m² in each paddock. A subsurface drip irrigation system was used for irrigation, with the drip tube buried in the soil at a depth of 0.20 m among the furrows of the double row. The drip tube (DRIPNET PC 16150) comprised a thin wall, 1.0 bar pressure, nominal discharge 1.0 L h⁻¹, and 0.50 m spacing between drippers. A 0.1 kPa puncture digital tensiometer was used to record daily readings of the soil matric potential (Ψm) in order to schedule irrigation. Four batteries of tensiometers were installed between the centerlines of the plots. The irrigation strategy was to irrigate to field capacity when the soil water tension exceeds -50 kPa, measured in the root-zone. The physical-hydro characteristics of the soil were determined by the water retention curve of the soil.

The van Genuchten model (van Genuchten, 1980) was adjusted to convert the measured matric potential (Ψm) to soil water content (θ), minimizing the sum of the squares of the deviations using the software SWRC (Dourado-Neto et al., 2000), thus, obtaining, the empirical parameters of adjustment used in the equation shown thus:

\[
\theta = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha \times |\Psi_m|)^n\right]^{m}}
\]

\[
\theta = 0.3027 + \frac{0.59 - 0.3027}{\left[1 + (0.0447 \times |\Psi_m|)^{1.7657}\right]^{0.43365238}}
\]

Wherein: θ – soil water content, cm³.cm⁻³; Ψm – matric potential, kPa (in module); θr – soil moisture saturated, cm³.cm⁻³; θs – soil moisture residual, cm³.cm⁻³; α, n, m – empirical parameters of adjustment.

Each battery of tensiometers consisted of sixteen tensiometric rods, that were installed at four depths (0.20; 0.40; 0.60; and 0.80 m of soil surface) and four horizontal distances from the dripline (0.15; 0.30; 0.45; and 0.60 m) (Figure 1). The readings of the tensiometers for soil matric potential record were performed from October 28, 2011 to March 13, 2012 (35 observations of soil matric potential), using a digital tensiometer of puncture (mark: Tensiometer). Was subtracted the length of the water column in the tensiometer from the reading to get the soil matric potential.

The values of soil matric potential were evaluated through mathematical regressions according to their depths under the ground surface and the horizontal distances of the tensiometric rods in relation to the dripline. Construction of the graphics was...
Table 1. Meteorological data and culture during the period of the experiment.

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2012</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month</td>
<td>Mar</td>
<td>Apr</td>
<td>May</td>
</tr>
<tr>
<td>P (mm)</td>
<td>109.7</td>
<td>23.5</td>
<td>0.2</td>
</tr>
<tr>
<td>ETo (mm)</td>
<td>74.4</td>
<td>63.5</td>
<td>48.6</td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>0</td>
<td>4</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: Normal weather station INMET A025 – Rio Verde, GO, Brazil. P - precipitation; ETo - crop evapotranspiration (Penman-Monteith/FAO). * In April irrigation was cut for harvest.

Table 2. Physical-hydro characterization of Dystrophic Red Latosol in the experimental area.

<table>
<thead>
<tr>
<th>Layer (m)</th>
<th>Granulometry (g kg⁻¹)</th>
<th>θ&lt;sub&gt;FC&lt;/sub&gt;</th>
<th>θ&lt;sub&gt;PWP&lt;/sub&gt;</th>
<th>Bd</th>
<th>TP</th>
<th>Textural classification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand</td>
<td>Silt</td>
<td>Clay</td>
<td>θ&lt;sub&gt;FC&lt;/sub&gt;</td>
<td>θ&lt;sub&gt;PWP&lt;/sub&gt;</td>
<td>g cm⁻³</td>
</tr>
<tr>
<td>0–0.20</td>
<td>458.30</td>
<td>150.20</td>
<td>391.50</td>
<td>51.83</td>
<td>30.50</td>
<td>1.27</td>
</tr>
<tr>
<td>0.20–0.40</td>
<td>374.90</td>
<td>158.30</td>
<td>466.80</td>
<td>55.00</td>
<td>31.33</td>
<td>1.28</td>
</tr>
</tbody>
</table>

θ<sub>FC</sub> - field capacity (10kPa); θ<sub>PWP</sub> - permanent wilting point (1500 kPa); Bd - soil bulk density; TP - total porosity.

Figure 1. Outline of W-shaped planting and the laying of driplines, demonstrating the location of the tensiometric rods for monitoring soil matric potential at different depths and horizontal distances from the dripline.

Table 3 presents the average values of 35 observations of soil matric potential (kPa), as well as the standard deviation and coefficient of variation for each depth and horizontal distance analysed. The values of the statistical parameters (average, standard deviation and coefficient of variation) for the data set of matric potential at depths of 0.40; 0.60; and 0.80 m were similar, causing low coefficients of variation. On the other hand, the highest coefficient of variation in the data on soil matric potential was observed at a depth of 0.20 m (average value of the coefficient of variation of 16.2%), whereas at the other depths a lower coefficient of variation (average value of the coefficient of variation of 4.6%) was seen (Table 3).

The values of soil matric potential as a function of depth for different horizontal distances from the dripline are presented in Figure 2. We observed increase in the matric potential with increasing depth, irrespective of the horizontal distance measured. The lowest values of the matric potential were obtained in readings from tensiometric rods located a distance of 0.60 m from the dripline. The proximity between the regressions obtained performed using the demo version of the app Sigma Plot 11.0 (Systat Software Inc®). A tridimensional graphic was constructed using the app Wolfram Mathematica versão 7.0. Linear regressions were compared to each other using the homogeneity test for linear models described by Snedecor and Cochran (1989). The homogeneity test for linear models considers two models that are compared by analysing the intercept “a”, the angular coefficient “b” and the homogeneity of the data (Araujo-Junior et al., 2011). When two linear regressions presented homogeneous data and there were no significant differences between their coefficients (“a” and “b”), the data were combined and a new regression was built using all the data (Iori et al., 2012).

RESULTS

The values of soil matric potential as a function of depth for different horizontal distances from the dripline are presented in Figure 2. We observed increase in the matric potential with increasing depth, irrespective of the horizontal distance measured. The lowest values of the matric potential were obtained in readings from tensiometric rods located a distance of 0.60 m from the dripline. The proximity between the regressions obtained
Table 3. Values of soil matric potential (kPa) in Dystrophic Red Latosol cultivated with sugarcane and irrigated by subsurface drip at different depths below the ground surface and horizontal distances from the dripline.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Horizontal distance (m)</th>
<th>Average</th>
<th>Standard deviation</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20</td>
<td>0.15</td>
<td>-26.02</td>
<td>4.26</td>
<td>16.36</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>-26.53</td>
<td>4.73</td>
<td>17.83</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>-25.77</td>
<td>3.56</td>
<td>13.81</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>-26.99</td>
<td>4.48</td>
<td>16.60</td>
</tr>
<tr>
<td>0.40</td>
<td>0.15</td>
<td>-22.86</td>
<td>1.80</td>
<td>7.87</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>-22.40</td>
<td>0.79</td>
<td>3.54</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>-22.03</td>
<td>1.70</td>
<td>7.70</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>-22.25</td>
<td>1.10</td>
<td>4.94</td>
</tr>
<tr>
<td>0.60</td>
<td>0.15</td>
<td>-20.43</td>
<td>1.51</td>
<td>7.38</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>-20.37</td>
<td>0.46</td>
<td>2.27</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>-20.43</td>
<td>0.56</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>-20.71</td>
<td>0.59</td>
<td>2.85</td>
</tr>
<tr>
<td>0.80</td>
<td>0.15</td>
<td>-21.00</td>
<td>0.71</td>
<td>3.37</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>-21.37</td>
<td>1.15</td>
<td>5.36</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>-21.39</td>
<td>0.92</td>
<td>4.28</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>-21.43</td>
<td>0.66</td>
<td>3.09</td>
</tr>
</tbody>
</table>

Average of 35 observations. CV - Coefficient of variation.

Figure 2. Linear regressions obtained from soil matric potential (kPa) as a function of depth below the ground surface (m) in Dystrophic Red Latosol cultivated with sugarcane and irrigated by subsurface drip, for four horizontal distances from the dripline.
from the matric potential data as a function of depth at different distances is shown in Figure 2.

Firstly, we compared the regressions obtained at distances of 0.15 and 0.30 m. Looking at the test of significance values, the data in both regressions were homogeneous with no significant differences between the linear (a) and angular (b) coefficients (Table 4). It can therefore be stated that both regressions are similar and describe the same conduct. Thus, the data forming the regressions at distances of 0.15 and 0.30 m were joined to form a new regression and compared with linear regression at a distance of 0.45 m.

The similarity between these two regressions was verified in the same way (data homogeneity and similarities between the linear and angular coefficients). Subsequently, the regression data obtained at 0.15; 0.30; and 0.45 m was combined and used to compose yet another regression, which was compared with the regression at a distance of 0.60 m. It was again verified that there were no significant differences between the linear and angular coefficients and that the data were homogeneous. Thus, it could be argued that all the data obtained for all the regressions can comprise a single regression as presented in Figure 3. The behaviour of this new regression was identical to the previous behaviour of the less comprehensive regressions, that is, increasing the depth of the monitoring caused increase in the tendency of the soil matric potential (Figure 3). The evidence of similarity in the matric potential regressions as a function of the tensiometric rod’s distance from the dripline up to 0.60 m demonstrates uniformity in the maintenance of soil moisture via distribution of water by a subsurface drip system. This result can be attributed mainly to the physical attributes of the soil type in the study (Dystrophic Red Latosol), allowing an expansion of the wetted zone that exceeded a radius of 0.60 m laterally, and underscoring that the moisture inside the bulb is relatively well distributed (Figure 2).

Figure 4 presents the regressions obtained from soil matric potential (kPa) as a function of horizontal distance from the dripline (m) for each depth evaluated. Among the four depths analysed, it was verified that the

Table 4. Significance test based on Snedecor and Cochran (1989) between the regressions obtained for soil matric potential as a function of depth below the ground surface at different horizontal distances from the dripline.

<table>
<thead>
<tr>
<th>Horizontal distance (m)</th>
<th>Data homogeneity</th>
<th>Angular coefficient, b</th>
<th>Linear coefficient, a</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15 x 0.30</td>
<td>0.56^H</td>
<td>0.00^NS</td>
<td>0.01^NS</td>
</tr>
<tr>
<td>0.15 and 0.30 x 0.45</td>
<td>0.62^H</td>
<td>0.13^NS</td>
<td>0.07^NS</td>
</tr>
<tr>
<td>0.15 and 0.30 x 0.45 x 0.60</td>
<td>0.44^H</td>
<td>0.05^NS</td>
<td>0.14^NS</td>
</tr>
</tbody>
</table>

^H - homogeneous; ^NS - not significant.
regressions obtained for depths of 0.20, 0.60 and 0.80 m presented similar behaviour (slope), that is, increasing the horizontal distance from the tensiometer relative to the dripline provided little reductions in the soil matric potential. The only exception occurred at a depth of 0.40 m, where increasing the tensiometer distance from the dripline provided a little increase in soil matric potential.

The depth of tensiometers, presenting specific regression, enabled the creation of a tridimensional model to better express the soil matric potential along the soil profile (Table 5). Thus, the variables were subjected to statistical methodology to check the deviation occurring between the observed and predicted data, to obtain a better representation of the behaviour of the matric potential as a function of depth beneath the ground surface and horizontal distance from the dripline (Figure 5). The dependent variable (soil matric potential) presented a strong relationship as a function of depth below the ground surface and horizontal distance from the dripline in the tridimensional space ($R^2 = 0.99$).
consequently, adapting the variable of interest to a function of two independent variables, the behaviour of the matric potential can be predicted with great accuracy, as exhibited in Figure 5.

DISCUSSION

According to the statistical parameters (average, standard deviation and coefficient of variation), for the data set of matric potential at depths 0.40; 0.60; and 0.80 m below the ground surface presented similar values between one another. This similarity in the data was confirmed by the low coefficients of variation observed for these three depths (0.40; 0.60; and 0.80 m). The higher coefficient of variation in soil matric potential at a more superficial depth reflects a greater influence of external conditions on the soil that caused these oscillations; for example, the air temperature, as well as greater variation in the water content of this layer during the year. The soil surface is more susceptible to climate, as daily temperature and solar radiation variation, and to anthropic interference, as tillage and soil management. Coelho and Teixeira (2004) also attributed small oscillations in the curves describing the monitoring of soil matric potential to temperature fluctuations. Azooz and Arshard (1994) also noted a decline in the readings of matric potential in tensiometers with increasing soil temperature.

In this regard Melo Filho and Libardi (2005), studying the temporal stability of soil water content and soil matric potential in determining hydraulic conductivity in an instantaneous profile, underscored the importance of using the coefficient of variation as a descriptive parameter of the matric potential's variability. Thus, according to the criteria of Warrick and Nielsen (1980) for classifying the coefficient of variation, at a depth of 0.20 m the coefficient of variation was classified as average (coefficient of variation between 12 and 60%), while the other depths all presented coefficients of variation classified as low (coefficient of variation less than 12%). To determine if each such regressions was similar, i.e., if they each presented a unique behaviour, these linear equations were compared by the test of homogeneity according to Snedecor and Cochran (1989) (Table 4). This methodology is widely used in field studies of soil science to compare linear regressions (Araujo-Junior et al., 2011; lori et al., 2012, 2013; Pais et al., 2013).

In this study, we obtained a linear relationship for soil matric potential as a function of the depth analysed. Martins (2009), studying the influence of the distance of installation of tensiometers in a field for calculating the
total potential gradient using the method of instantaneous profiling, verified that the total potential of the data as a function of soil depth adjusted to a quadratic equation. The regressions presented in Figure 4 were compared among themselves using the same methodology used previously, by the significance test according to Snedecor and Cochran (1989) (Table 5). Firstly, the regressions obtained at depths of 0.20 and 0.40 m were compared. This comparison showed that these regressions presented different linear coefficients ("a"); thus, these regressions were not similar, and each regression must be predicted by its own data. In the subsequent comparison, there were always significant differences, either in angular coefficient or linear coefficient, or insufficient data homogeneity. Therefore, each depth must be predicted using its respective data, that is, each depth presented must be specifically regressed. Consequently, the depths presented different and specific patterns. These results are similar to those obtained by Souza et al. (2007), who observed greater availability in water readings after an hour of irrigation at a depth of 0.65 m with a drip buried 0.25 m beneath the soil surface.

The soil matric potential is indirectly related to soil moisture, by having a, higher soil water content, at lower the matric potential (Bezerra et al., 2012). The regression shown in Figure 5 indicates that the lowest matric potential occurred at a depth of 0.68 m below the soil surface, with a value of 20.34 kPa (in module). The horizontal distance from the drip line did not have an effect on this result, due to better circulation of water in the soil, through increased permeability and proportionate suction, especially for the root system of the plants, which directly influences the flow behaviour of soil water (Bezerra et al., 2012). Moreover, Ajayi et al. (2009) confirmed that Latossols in the Cerrado region features a predominantly oxidic mineralogy and granular type structure, giving the latter soils high porosity.

With regards to the lateral movement of soil moisture from the buried drip system, the uniformity of the wetted diameter at different points on the soil surface was observed (Figure 4). According to Barros et al. (2009), subsurface drip irrigation systems allow the formation of a more dispersed wetted bulb, that is, despite having a smaller surface area of wetted soil in relation to the surface drip, the water applied reaches more distant points in the soil, both in depth as well as lateral distance from the dripline.

Conclusions

The depth of the tensiometers rods in the profile of Dystrophic Red Latossol contributed to the monitoring of soil matric potential via subsurface drip irrigation in sugarcane cultivation. Water storage in the soil was of low spatial variability in the horizontal direction, reflecting a high homogeneity in the level of moisture out to a lateral distance of 0.60 m from the dripline.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

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Oliveira et al. 3299


