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WET BULBS FROM THE SUBSURFACE DRIP IRRIGATION WITH WATER SUPPLY AND TREATED SEWAGE EFFLUENT

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ABSTRACT: The use of treated sewage effluent (TSE) combined with the subsurface drip irrigation (SDI) method in agriculture can decrease the costs of agricultural production, in attempts to fertigate crops more efficiently. In this study it was compared the dimensions of the wet bulb formed by the application of TSE and municipal water supply (MWS) in an Oxisoil. We have evaluated the effect of water quality and discharge between drippers used in sugarcane crop. Three trenches were opened and 21 three-rod TDR probes were setup in a mesh and a dripper was buried at 0.30 m, for each constant discharge of 1.0 L h⁻¹ and 1.6 L h⁻¹. Comparing results from different wetted soil profiles it was observed that the vertical and horizontal dimensions of the wet bulb are similar for both MWS and TSE, being peculiar according to the discharges used and volume applied. Regardless the water quality, an increase of 60% in discharge decreased the deepest infiltration.

KEYWORDS: oxisoil, wastewater; TDR; water content; electrical conductivity.

BULBOS ÚMIDOS A PARTIR DA IRRIGAÇÃO POR GOTEJAMENTO SUBSUPERFICIAL COM ÁGUA DE ABASTECIMENTO E EFLUENTE DE ESGOTO TRATADO

RESUMO: O uso de efluente de esgoto tratado (EET), combinado com o método de irrigação por gotejamento subsuperficial (IGS) na agricultura, pode reduzir os custos de produção agrícola, fertirrigando de maneira eficiente as culturas. Neste artigo, compararam-se as dimensões do bulbo úmido formado pela aplicação de EET e água de abastecimento municipal (AAM), em um Latossolo Vermelho distroférico. Avaliou-se o efeito da qualidade da água e da vazão entre gotejadores utilizados na cultura da cana-de-açúcar. Três trincheiras foram abertas e 21 sondas de TDR com três hastes foram instaladas em malha, e um gotejador foi enterrado a 0,30 m, para cada vazão constante de 1,0 Lh⁻¹ e 1,6 Lh⁻¹. Comparando os resultados de diferentes perfis de umidade do solo, sugere-se que as dimensões vertical e horizontal do bulbo úmido sejam similares para a AAM e para o EET, sendo peculiares de acordo com as vazões utilizadas e o volume aplicado. Independentemente da qualidade da água, o aumento de 60% na vazão reduziu a infiltração em profundidade.

PALAVRAS-CHAVE: latossolo vermelho distroférico; águas residuais; TDR; umidade; condutividade elétrica.

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INTRODUCTION

Although profitable, irrigated agriculture is the human activity responsible for increasing water demand in worldwide generating conflicts in relation to other water uses.

Growing competition over dwindling water resources in many agricultural areas in Brazil increases the use of marginal quality water with drip irrigation, which requires sound fertigation practices that reconcile environmental concerns with viable crop production objectives. In this context, the subsurface drip irrigation system becomes gradually popular as a means to supply water more efficiently contributing to increment agricultural productivity (CAMP, 1998). In São Paulo/Brazil the use of irrigation system, such as the subsurface, is also a technical viability to rise the productivity levels of sugarcane, due to the high cost of production areas (BARROS et al., 2009).

Nowadays there is a worldwide trend aiming at using treated sewage effluent (TSE) for crop irrigation. In addition, the combined use of TSE and subsurface drip system supply more effectively the required amount of water and nutrients to the plant and it is a practice of water reuse and preservation of water resources (BEGGS et al., 2011). This practice aims the sustainable use of the hydric resources and implements the concept of modern agriculture that seeks not only to increase the tillage production, but also press for the preservation of the environment. In this case the soil is used as a debugger and decreases the contamination risk of the environment, allowing its use for the TSE application. Indeed, particular caution must be taken with this practice in agriculture, since successive TSE applications may cause soil salinization (TAVARES et al., 2011).

In the midst of various drip irrigation systems used, the subsurface applies water directly to the root zone forming the wet bulb. In this region, the soil water content keeps close to the field capacity and evaporative losses are minimized. Nevertheless, it is necessary to know the support capacity of each soil-plant system in order to establish the most appropriate application rate by preserving the integrity of natural resources. Moreover, reports on changes in soil physical properties and leaching of nitrate or other mobile contaminants have crucial importance (LEAL et al., 2009). In Brazil the use of TSE for agricultural irrigation is still a recent practice and, consequently it demands more studies with detailed information on its benefits and drawbacks under tropical conditions (Da FONSECA et al., 2007).

The wet bulb sizing assists in proper estimate the number of drippers per plant and its location relative to the plants or plant rows, directly influences the project costs of irrigation and crop yields. Unfortunately, these sizing are often overlooked and current practices in Brazil and elsewhere in the world are too often based on empirical information or on data gleaned indiscriminately from professional literature. Alternatively, according to SOUZA et al. (2009) the shape of a wetted soil volume can be measured and controlled using water content sensing equipment, such as time domain reflectometry (TDR), which measures water content and electrical conductivity using a single probe within the same soil volume. Although several studies that investigate the wet bulbs sizing in subsurface drip irrigation are available in the literature, none use the TSE with the TDR technique to monitor the dynamic of the water and the solute.

In this study we shaped and compared the dimensions of wet bulbs in subsurface drip irrigation with MWS and TSE, for each constant discharge of 1.0 L h^{-1} and 1.6 L h^{-1} . Our findings contribute to underpin the design and the management of sugarcane fertigation, which constitute one of the most promising target culture in Brazil, decreasing the costs with fertilizers and water consumption, evaluating concomitantly possible impacts of the TSE in the environment.

MATERIAL AND METHODS

The field experiment was performed during 2011 at the College of Agricultural Engineering in the University of Campinas - Brazil, with geographic coordinates $22^{\circ}81' 89''$ South latitude and $47^{\circ}06'22''$ West longitude. The soil of the study area is classified as Oxisoil, medium to clayey

texture, according to criteria set by (EMBRAPA, 1999). Table 1 lists the initial soil physical characteristics.

TABLE 1. Physical characteristics of the soil in field condition

Depth (m)	Bulk Density (Kg m ⁻³)	Total Porosity (%)	Texture (g Kg ⁻¹)			K _{sat} (m h ⁻¹)
			Clay	Silt	Sand	
0-0.2	1306	51.0	580	170	250	0.032
0.2-0.4	1258	49.0	590	170	240	0.031
0.4-0.6	1205	52.0	640	140	220	0.033
0.6-0.8	1186	51.0	660	130	210	0.033

K_{sat} saturated hydraulic conductivity

The experiment was based on the flow rate 1.0 L h⁻¹ and 1.6 L h⁻¹, and the water quality classified as municipal water supply (MWS) and treated sewage effluent (TSE). The effluent used comes from the College of Agricultural Engineering, which is composed by sanitary and domestic wastes. It is treated in an up-flow ascendant sludge blanket (UASB) and subsequently forwarded to the “wetlands” for a secondary treatment.

In Brazil the National Environment Council (CONAMA) by the resolution 357, March 17, 2005, establishes provisions for the classification of environmental directives for the framing of superficial water bodies as well as for the establishment of conditions and standards related to dumping into effluents. Specifically for irrigation, the fresh water is classified as Class 1, 2 and 3 according to quality limits for chemical, physical, and biological parameters. These limits were used to compare and discuss the results for the TSE and the MWS.

The Figure 1A shows the scheme setup of the 21 three-rod TDR probes and the dripper position. The Figure 1B illustrates the field assembly. The TDR probes were placed at 0.15, 0.25, 0.35, 0.45, 0.55 and 0.65 m – in depth, and 0.05, 0.15, 0.25 and 0.35 m – distance from the dripper (totaling 21 probes). This layout was described in detail by BARROS et al. (2009). The three-rod probes TDR used in the experiment were built in the laboratory of hydraulic and irrigation and the constructive details are described in SOUZA et al. (2006). Each TDR probe provided spatial and temporal information on water content and solute concentration in the soil thus, enabling detailed monitoring of water and solute dynamics. In two opposite walls of each trench this procedure was replicated using a pressure-compensating dripper (Netafim - DripNet PCTM AS 16150) buried at 0.30 m for each constant discharge of 1.0 L h⁻¹ and 1.6 L h⁻¹. According to PIRES et al. (2008) this depth value is ideal for sugarcane irrigation. As recommended by BARROS et al. (2009), LOPES et al. (2010) and, LOPES et al. (2009) the irrigation was set off after two months aiming at the soil restructuring.

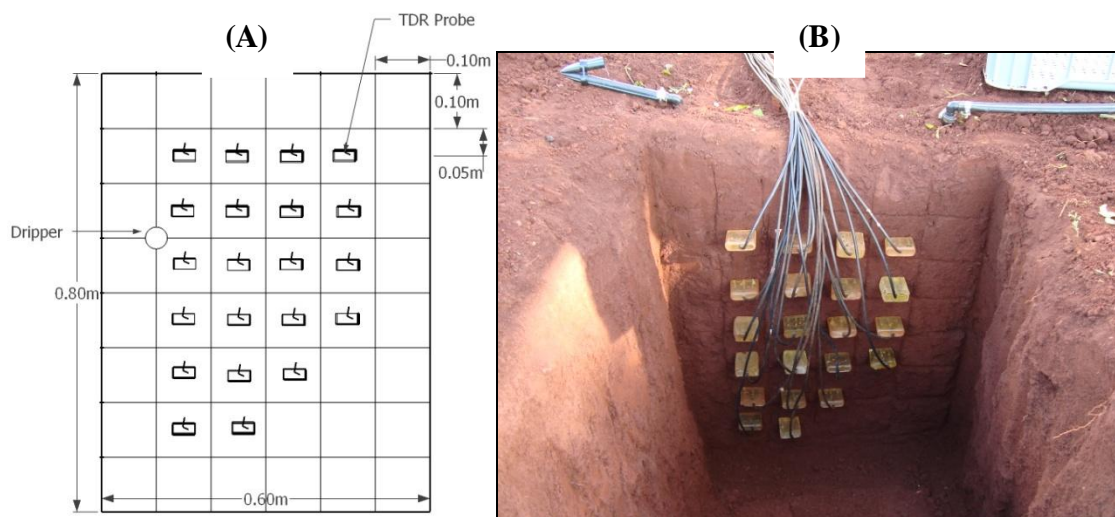


FIGURE 1. (A) Scheme of the experimental setup for probes and dripper; (B) Field assembly

Firstly the soil was irrigated with MWS for both flow rates of 1.0 L h^{-1} and 1.6 L h^{-1} . The monitoring of water distribution was performed before the irrigation with 10 L of water and afterwards. The data logger was set up to a frequency of data acquisition of 1 hour. For the MWS evaporation, we awaited a period of 15 days to set off irrigations with (remover “the”) TSE. No rains were reported during this period. This methodology was developed based on the research of COELHO & OR (1999).

Using the Reflectometer TDR 100 equipped with RS 232 interface and data collector CR 1000, we monitored the water content and electrical conductivity analyzing the electromagnetic signal.

The schedule of the readings were based on the application of MWS and TSE by each dripper at a time, with the 21 readings being carried out in real time using the multiplexers SDMX 50. The TDR requires a calibration equation to convert measured bulk dielectric permittivity (Ka) to soil water content (θ). In this study we used the equation based on the research of ROQUE (2007) as follows:

$$\theta = 20,03 + 0,548Ka \quad (1)$$

Due to the estimation of apparent electrical conductivity, the TDR based on the probe characteristic impedance was obtained together with the volumetric water content values. As all the probes used in this study were constructed at the University of Campinas, the characteristic impedance parameter of the probes was measured before its installation at the field.

We used the surface mapping (Surfer 8.0) to achieve a better understanding and comparison of the dynamics of water and solute in the soil. The Kriging option was used as the interpolation method, because according to SEO (2011), using this technique is possible to predict the special values in the region of interest through the weighting linear function that is measured from the nearby known values.

RESULTS AND DISCUSSION

Data presented in Table 2 show the physicochemical characteristics of the TSE and the MWS, used for irrigation and analyzed based on the standard method APHA (2012).

Regarding to heavy metals, data show that Co, Cr, Zn, Cu, Ni, Mn, Pb, Cd, and Hg are under CONAMA limits in all classes, for both TSE and MWS. According to DURUIBE et al. (2007) the presence of a pollutant in the environment, such as heavy metals, has to be beyond a set or tolerance limit, which could be either a desirable or acceptable limit.

There is a significant difference among the levels of total nitrogen, nitrate, and nitrite in the TSE suggesting low efficiency of the nitrification process in the treatment system. The oxidation of organic nitrogen in the soil to nitrate can be leached below the root zone and contaminate the ground water, as reported in Runnel Country, Texas during the period 1900-1950 (KREITER & JONES, 1975).

TABLE 2. Physicochemical characteristics of the TSE and the MWS

Parameter	TSE	MWS
Aluminium (Al) mgL ⁻¹	0.04	0.23
Boron (B) mgL ⁻¹	0.10	LOD
Calcium (Ca ⁺²) mgL ⁻¹	18.3	4.59
Cobalt (Co) mgL ⁻¹	< 0.005	< 0.001
Copper (Cu) mgL ⁻¹	< 0.005	< 0.005
Sulfate (SO ₄ ⁻²) mgL ⁻¹	< 2.50	<5.00
Iron (Fe) mgL ⁻¹	1.60	0.47
Total Phosphorus (P-total) mgL ⁻¹	8.30	0.19
Magnesium (Mg ⁺²) mgL ⁻¹	3.20	2.77
Manganese (Mn) mgL ⁻¹	0.07	0.03
Molybdenum (Mo) mgL ⁻¹	< 0.01	< 0.001
Nickel (Ni) mgL ⁻¹	< 0.1	< 0.1
Total Nitrogen (N-total) mgL ⁻¹	66.70	3.20
Nitrate (NO ₃ ⁻) mgL ⁻¹	< 0.50	< 0.30
Nitrite (NO ₂ ⁻) mgL ⁻¹	< 0.10	< 0.01
Potassium (K ⁺) mgL ⁻¹	27.00	0.85
Sodium (Na ⁺) mgL ⁻¹	57.60	1.61
Zinc (Zn) mgL ⁻¹	0.10	0.03
Lead (Pb) mgL ⁻¹	< 0.01	< 0.001
Cadmium (Cd) mgL ⁻¹	< 0.001	< 0.001
Chromium (Cr) mgL ⁻¹	< 0.01	< 0.001
Mercury (Hg) mgL ⁻¹	<0.0015	< 0.0001
Total Chlorine (Cl) mgL ⁻¹	< 0.01	< 0.01
BOD mgL ⁻¹	7.48	2.26
Electrical conductivity (EC) dsm ⁻¹	0.98	0.05
pH (20° C)	7.44	9.13
SAR (mmolc L ⁻¹)	3.26	0.14

The treatments used in this field experiment were encoded to facilitate the discussion of the results as: Municipal water supply flow rate 1.0 L h⁻¹ (W1), Treated sewage effluent flow rate 1.0 L h⁻¹ (E1), Municipal water supply flow rate 1.6 L h⁻¹ (W1.6) and Treated sewage effluent flow rate 1.6 L h⁻¹ (E1.6). Due to the large number of figures, the wet bulbs chosen to represent the profiles were the 1,3,5,7,10 L to 1.0 L h⁻¹ and 1,3,5,8,10 L to 1.6 L h⁻¹.

The Figures 2 and 3 show the water content profiles for each application (from 1 to 10 L) of the MWS and the TSE using a flow rate of 1.0 L h⁻¹. Each contour line represents an increase of 0.01 m³ m⁻³. The results show that the drippers' discharge and physical properties of the soil perform different effects on the shape of the wet bulb. In accordance with the water content values obtained with the TDR can be noted that the bulbs have submitted feature forms. The volume of water applied shape bulbs, rounded and elliptical, similar to those described by ZUR (1996).

The vertical dimensions of the bulb are represented by the axes (+z) and (-z) from the emitter point shown by semicircle. The axis (r) represents the largest radial distance achieved by the wetting front during the applications.

It can be noted an accentuated downward water movement relative to lateral spreading. The downward dimension (-z) reached by the wetting front is in accordance with KOFFLER (1986), since is ideal for providing water at the effective root system of sugar cane, and avoiding water stress.

The spacing between emitters proposed by the manufacturer of the drippers, which we used in this experiment, is 0.55 m for the flow rate of 1.0 L h⁻¹. Evaluating the radial dimension from the wetting front after the last application can be seen that, in both treatments there is a singularity between this dimension and the spacing suggested by the manufacturer. This horizontal radius value for treatments W1 and E1 is approximately 0.20 m, and represents nearly half the distance between the emitters, assuming the formation of a continuous horizontal band of water content along the irrigation line.

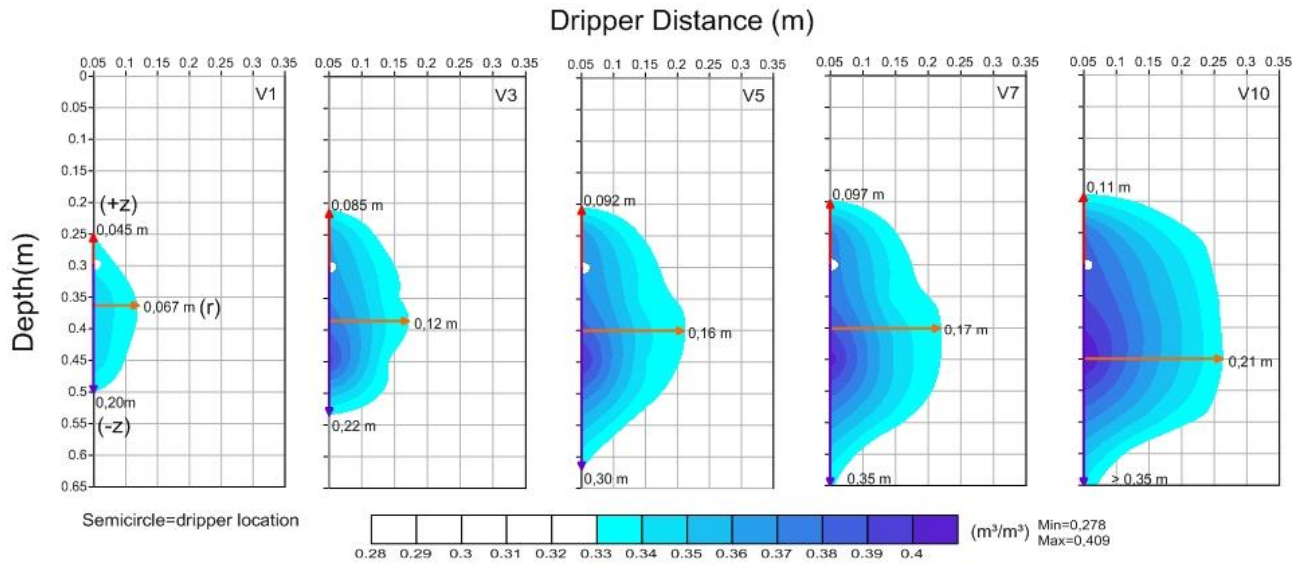


FIGURE 2. Soil water content profiles ($m^3 m^{-3}$) at the end of the infiltration process of each application of MWS at a flow rate of $1.0 L h^{-1}$.

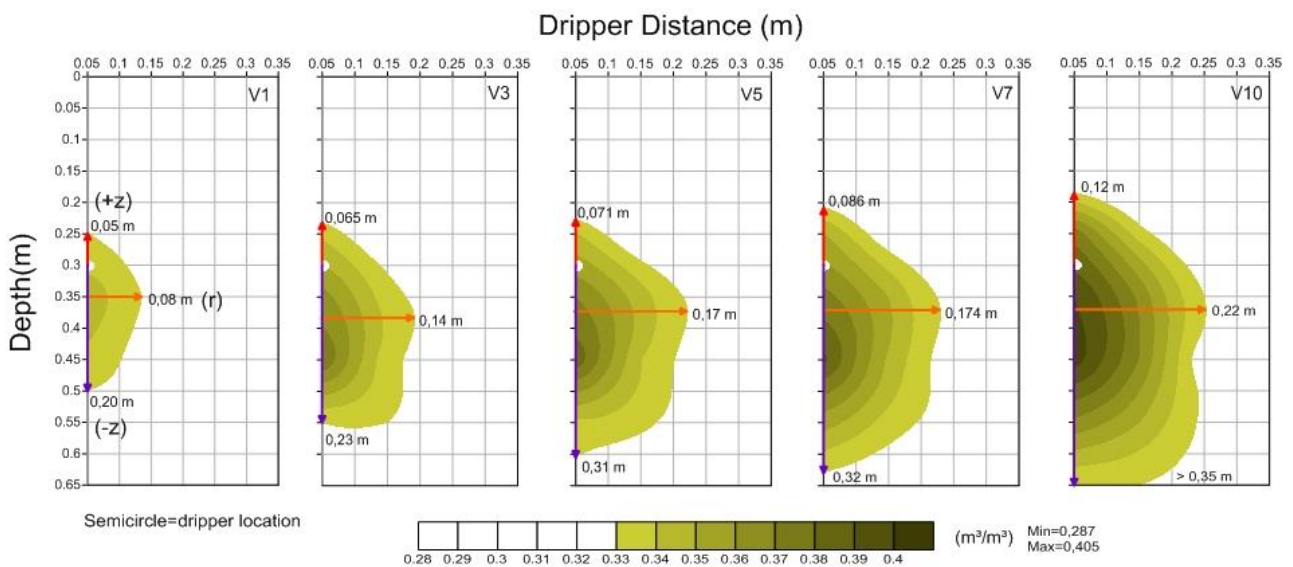


FIGURE 3. Soil water content profiles ($m^3 m^{-3}$) at the end of the infiltration process of each application of TSE at a flow rate of $1.0 L h^{-1}$.

The Figure 4 shows the linear regressions between the dimensions (+z), (-z) and (r) for the treatments W1 and E1. Notice that the correlation coefficients of dimensions (-z) and (r) are satisfactory and there is an association between linear equivalent dimensions (-z) and (r). However, the correlation coefficient of dimension (+z) does not provide an acceptable association. An apparent explanation for this fact would be the occurrence of possible changes in soil physical properties during the installation of the drip pipe, even though we awaited a period of two months for its restructuring.

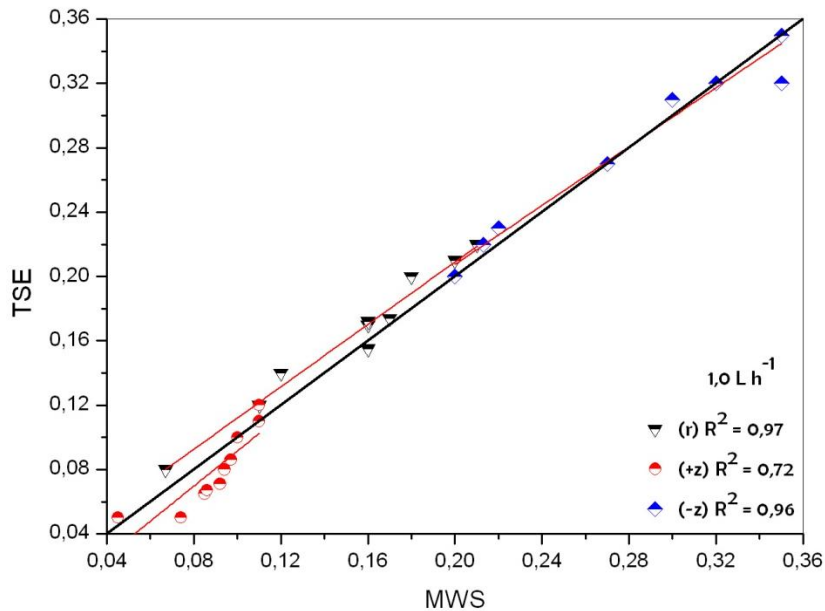


FIGURE 4. Linear regressions between the bulb dimension (+z, -z and r) for each application of MWS and TSE and the respective correlations for 1.0 L h^{-1}

The Figures 5 and 6 present the wet bulbs for treatments W1.6 and E1.6. It is noted in these treatments that the bulbs have submitted feature forms rounded and elliptical, as described by ZUR (1996). These shapes can also be seen in KANDELOUS et al. (2011) when comparing observed and simulated water contents profiles obtained from bulbs of subsurface dripping irrigation on clay soil at 0.30 m deep.

As observed, increasing the discharge of the dripper to 1.6 L h^{-1} increases the horizontal radius. However, decreasing the discharge to 1.0 L h^{-1} increases the vertical radius of the wet bulb. It happens due to the change of the infiltration area according to the treatments, but it is important to notice that regardless the water quality an increase of 60% in discharge decreases the deepest infiltration. It was also described by LOPES et al. (2009), thus confirming the findings presented here. Moreover, the discharge rate is directly proportional to the soil water content around the dripper, as described by DIAMANTOPOULOS, (2009).

In addition, the spacing between emitters proposed by the manufacturer of the drippers is 0.65 m for the flow rate of 1.6 L h^{-1} , which is the same explanation given for the horizontal dimension of discharge of 1.0 L h^{-1} . Therefore, we also propose an occurrence of a continuous horizontal band of water content along the irrigation line.

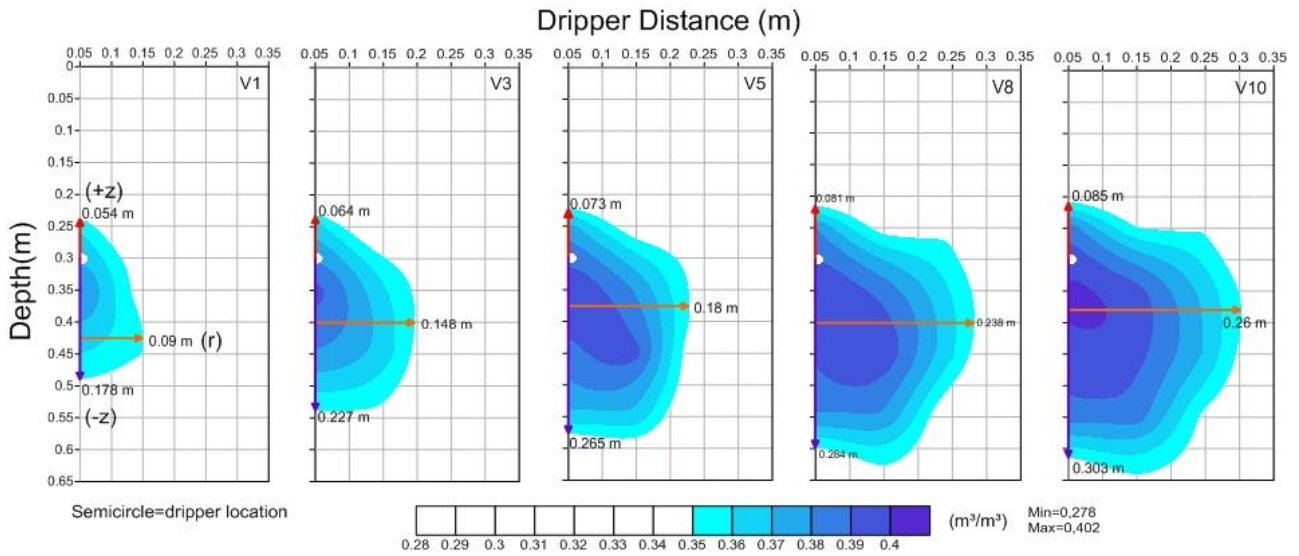


FIGURE 5. Soil water content profiles ($\text{m}^3 \text{m}^{-3}$) at the end of the infiltration process of each application of MWS at a flow rate of 1.6 L h^{-1} .

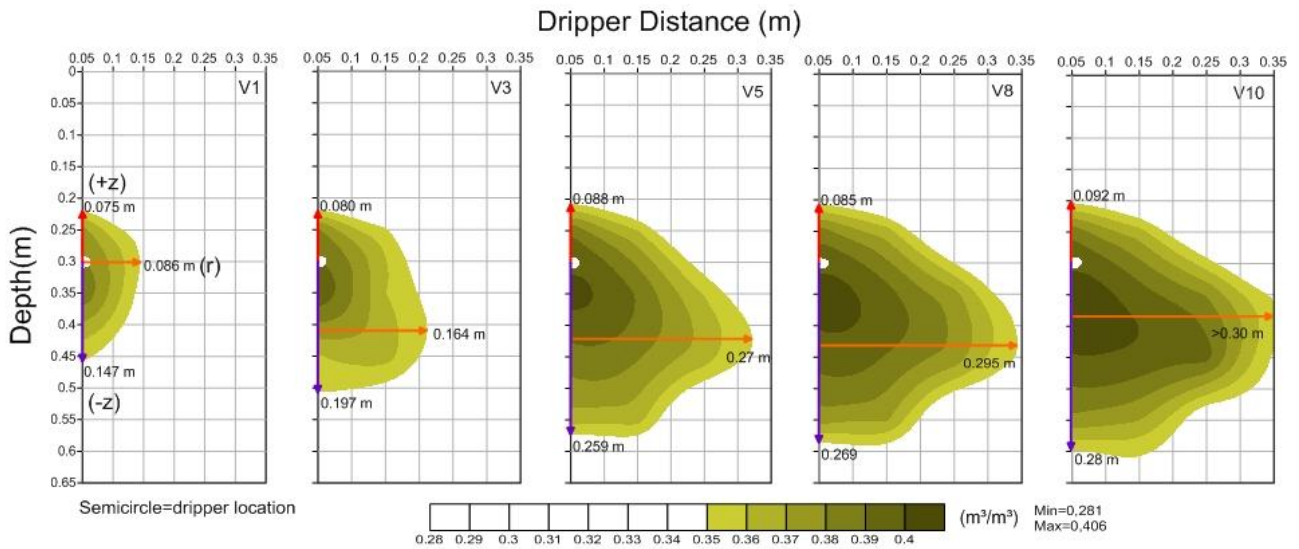


FIGURE 6. Soil water content profiles ($\text{m}^3 \text{m}^{-3}$) at the end of the infiltration process of each application of TSE at a flow rate of 1.6 L h^{-1} .

The Figure 7 shows the correlation coefficients of dimensions (+z), (-z) and (r) for the treatments W1.6 and E1.6. Can be seen that there is an association between linear equivalent dimensions (-z) and (r). As in treatments W1 and E1, the correlation coefficient of the dimension (+z) does not provide an acceptable association between W1.6 and E1.6. This concurs with the previously suggested hypothesis about possible changes in soil physical properties during the installation of the drip pipe.

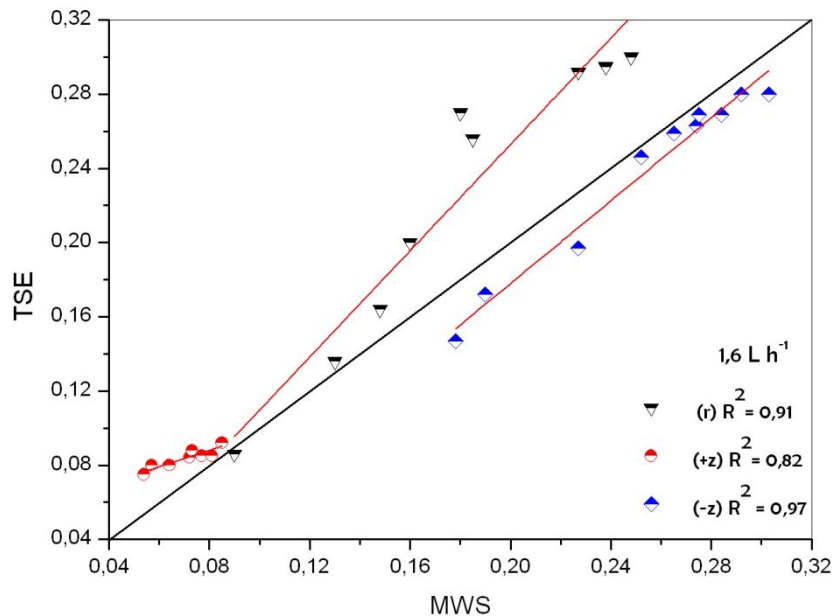


FIGURE 7. Linear regressions between the bulb dimension (+z,-z and R) for each application of MWS and TSE and the respective correlations for 1.6 L h^{-1}

The Figures 8 and 9 show the electrical conductivity (EC) of the TSE as a function of water content estimated by TDR. We considered the flow rates of 1.0 L h^{-1} and 1.6 L h^{-1} . It can be observed that the bulbs shaped by interpolating the values of EC show similar format when compared to the water content bulbs. However, it can be noted a reduction in the dimensions of axes (+z), (-z) and (r). LOPES et al. (2010) observed the same occurrence and suggested that the ions come forward in advance of water, and it moves slightly ahead of solutes toward to the extreme of the bulb. This delay is defined as sorption, which the speed of the chemical species is less than the speed of the groundwater. It includes the adsorption that is a physicochemical process in which the molecular attraction connects the solute to the solid surfaces such as, rock or soil particles. The materials that behave as absorbents are clays, oxy-hydroxides of Fe and Al and organic substances. Therefore, we used in this study a clay soil and its capacity to retain ions and its ion exchange explain the bulb reduction when dimensioned by the electrical conductivity parameter.

Considering as a reference the dripping point and comparing the dimension (-z) for both flow rates 1.0 L h^{-1} and 1.6 L h^{-1} the ions in the TSE tends to reach greater depths in the lowest flow. Besides, the nitrates are very soluble, have high mobility in soils and are easily transported in depth affecting the quality of groundwater (ABAIDOO et al., 2009). Moreover, the interactions between the different soil water content and solute concentration distribution, which presents a spatial gradient with greater storage of solutes near the dripper and gradual decrease towards the wetting front.

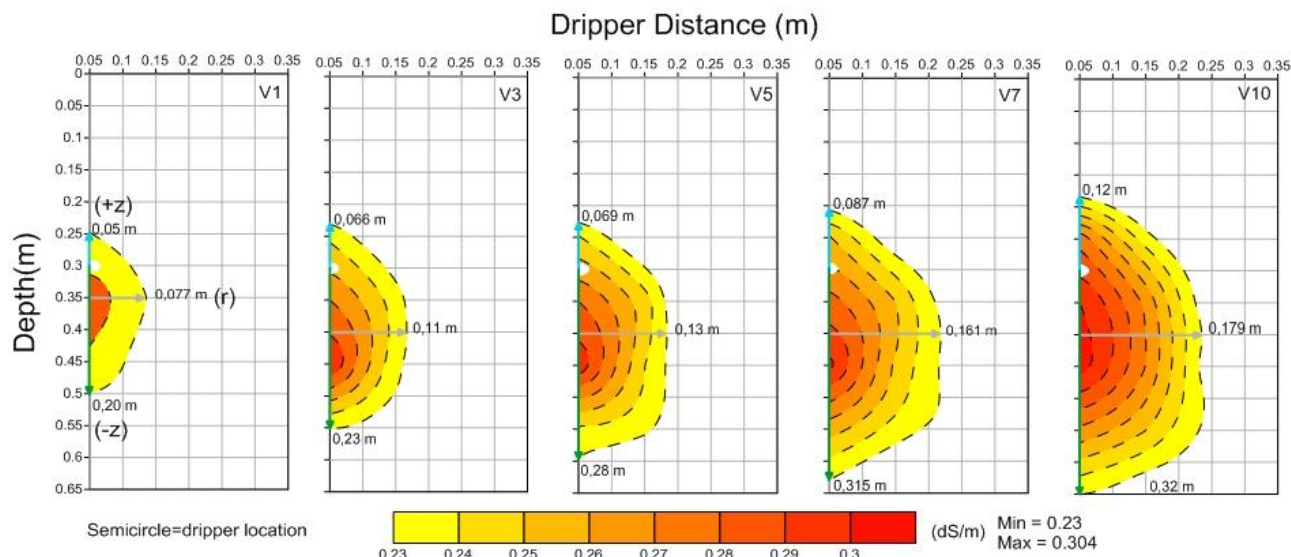


FIGURE 8. Distribution of electrical conductivity in the soil, 1.0 L h^{-1}

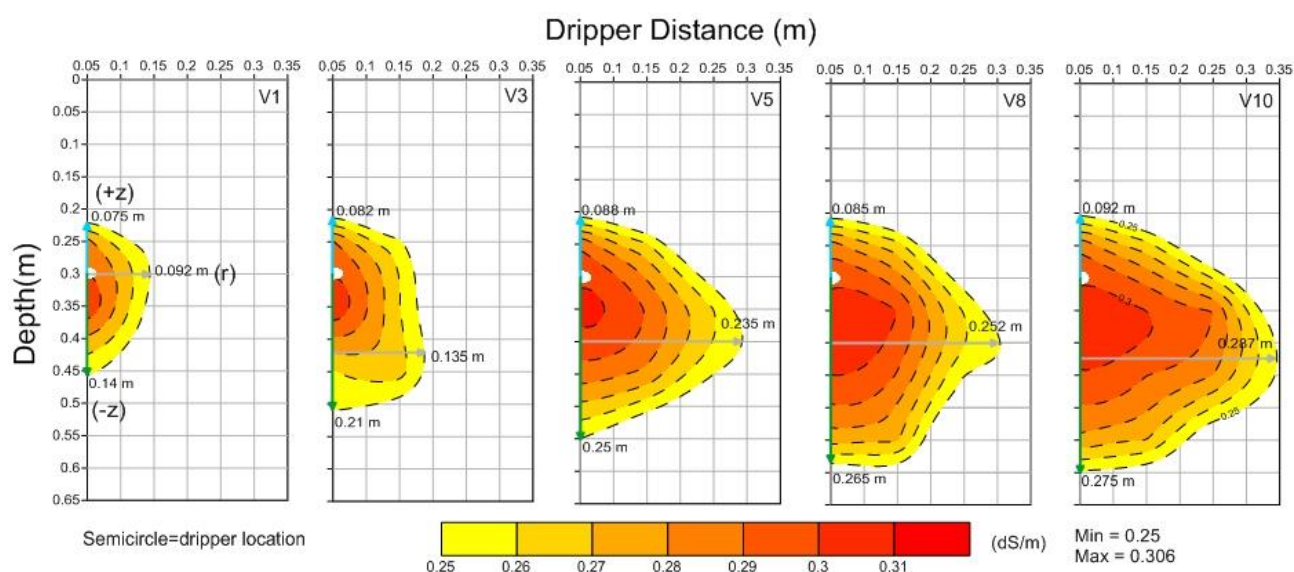


FIGURE 9. Distribution of electrical conductivity in the soil, 1.6 L h^{-1}

CONCLUSIONS

The following conclusions may draw from the results: (1) There were no differences between the dimensions of the wet bulb formed from the application of MWS and TSE to the flow rate of 1.0 L h^{-1} in an Oxisoil at 0.30 m of depth, as well as to the flow rate of 1.6 L h^{-1} ; (2) The interactions between the different profiles (water content versus electrical conductivity) revealed a gradient distribution of the solute in the soil near the emitter, decreasing progressively towards the wetting front; (3) Increasing the flow rate from 1.0 L h^{-1} to 1.6 L h^{-1} raised the horizontal radius of the wet bulb suggesting a wider spacing between drippers, such as recommended by the manufacturer of the drifter; (4) The concept of rational use of water by the use of TSE allied to subsurface drip irrigation in itself is environmentally positive, although the short term assessment of the TSE irrigation did not allow us to predict possible environmental impacts.

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