ISSN 2175-6813
Revista Engenharia na Agricultura
V.28, p.100-108, 2020
Viçosa, MG, DEA/UFV - DOI: 10.13083/reveng.v28i.950

TECHNICAL NOTE:

MONITORING XYLEM SAP IN SUGARCANE THROUGH TDR

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Keywords:
subsurface irrigation
Time Domain Reflectometry
water management

ABSTRACT

The TDR can be used to measure water content and nutrients in several media with a potential to monitor the xylem sap flow in plants. The objective of this study was to determine whether there is a correlation between the xylem sap content and water available in the soil for sugarcane cultivation using TDR. The study was conducted in a protected environment with eight boxes (500 L). The boxes were divided into two treatments with different water application rates (1.6 and 3.4 L h^{-1}) through subsurface irrigation. In each box TDR probes were inserted in the medium part of sugarcane stalk, totaling three probes per box to monitoring the sap flow. The soil water content was monitored using 20 net-placed probes. Therefore, the simultaneous monitoring of xylem sap and soil water content occurred for five months. As a result, it was obtained that the xylem content monitoring through TDR is moderately related to soil moisture, with a response to the absorption and translocation of the solution in the stem of sugarcane plants as a consequence of irrigation applications and/or fertirrigation. Thus, it was concluded that there is a weak relations between water contents in the soil and plant, especially for the treatment that used the highest flow rate (3.4 L h^{-1}).

Palavras-chave:
irrigação subsuperficial
manejo da água
Reflectometria no Domínio do Tempo

MONITORAMENTO DA SEIVA XILEMÁTICA EM CANA-DE-AÇÚCAR ATRAVÉS DA TDR

RESUMO

A TDR pode ser usada para medir o teor de água e nutrientes em diversos meios, com potencial para monitorar o fluxo da seiva xilemática. O objetivo deste trabalho foi determinar se há correlação entre o conteúdo de seiva xilemática e a água disponível no solo para a cultura da cana-de-açúcar utilizando a técnica da TDR. O estudo foi realizado em ambiente protegido, no qual oito caixas com solo (500 L) foram divididas em dois tratamentos com diferentes taxas de aplicação de água (1,6 e 3,4 L h^{-1}) por irrigação subsuperficial. Em cada caixa, foram inseridas sondas TDR na parte mediana do caule de cana-planta, totalizando três sondas por recipiente para o monitoramento do fluxo de seiva. Para o monitoramento de água no solo utilizou-se 20 sondas dispostas em malha. Desta forma, o monitoramento simultâneo do fluxo de seiva e água no solo ocorreu durante cinco meses. Como resultado, obteve-se que o monitoramento do conteúdo xilemático através da TDR está moderadamente relacionado com a umidade do solo, havendo uma resposta à absorção e translocação da solução no caule das plantas de cana-de-açúcar em consequência das aplicações via irrigação e, ou, fertirrigação. Assim, concluiu-se haver fraca relação entre os conteúdos de água no solo e na planta, principalmente, para o tratamento que utilizou a maior vazão (3,4 L h^{-1}).

Recebido para publicação em 10/09/2018 • Aprovado em 11/09/2019 • Publicado em 06/02/2020

INTRODUCTION

Irrigated agriculture tends to grow in the future, considering the more and more constant climate change and droughts. As it is the sector that uses water the most, the biggest challenge for the future is the search for water optimization in agriculture, which will reduce the pressure on water resources and making water available for other purposes. Innovations to rationalize the use of water and avoid or reduce waste will be important means to attend the increased demand for food (LOPES & CONTINI, 2012).

Knowing the water content in the soil (moisture) and its distribution are important parameters in many disciplines related to the soil, such as Soil Science, Farming, Forestry and Hydrology (FATÁS et al., 2013). For accurate estimates of moisture and soil solution concentration, there is a tendency to use the Time Domain Reflectometry (TDR) technique, in the laboratory and in the field.

Time Domain Reflectometry (TDR) consists of generating a high frequency electromagnetic pulse through a pair of conductors (denominated transmission lines) and detecting its reflection. There will be discontinuities along the stainless steel transmission lines, which, when reflected, will form waves. Through the location of waves reflected in the time domain, and the spatial determination of pulse discontinuities, it is possible to determine the soil dielectric properties (PANDEY et al., 2013).

A disadvantage associated with this technique is the need for calibration, in addition to the high cost of acquiring the equipment (SONCELA et al., 2013). However, TDR stands out for being an accurate, portable, non-destructive and easy to handle method (SOUZA et al., 2013). PAVÃO et al. (2014) used the technique in sugarcane plants and concluded that smaller probes can bring better results if the plant tissues are not damaged. Moreover, as this is a field experiment, the authors were unable to establish continuous monitoring of soil moisture and in the plant tissues.

The economic interest in sugarcane has increased significantly in the last years due to the raise in the world's demand for the production of sustainable energy. In the future, biotechnological advances may help to reduce the environmental impacts caused by the increment in the production through solutions that produce more by requiring reduced amounts of water and fertilizers (CHEAVEGATTI-GIANOTTO, 2011). Thus, water management in the sugar cane cycle is of great importance in order to improve the efficiency in the use of water.

The objective of this work was to determine if there is a correlation between the content of xylemic sap and the amount of water available in the soil for the cultivation of sugarcane using the TDR technique.

MATERIAL AND METHODS

The work was developed in a greenhouse at the Center for Agricultural Sciences (CCA) of the Federal University of São Carlos (UFSCar), located in the city of Araras, state of São Paulo, at latitude 22°18'53" S and longitude 47°23'01"W at 701 m above sea level. The greenhouse has a galvanized structure, with an arc-roof and plastic cover, closed by a screen on the sides, with 20.0 m in length by 6.4 m in width and 5.0 m in height.

For determination of a physical analysis of the soil, samples were removed from volumetric rings at 0-0.15 m and 0.15-0.30 m depths. The samples were taken to the Laboratory of Soil Physics and Water Quality at the university, and the analysis results are shown in Table 1. During the accommodation of the soil in the boxes, we sought to approximate the density of the soil to that obtained through physical analysis

Inside the greenhouse, PVC boxes with dimensions of 0.65 m in height and 1.20 m in diameter were distributed, totaling eight boxes, forming two rows of four containers on opposite sides as shown in the diagram below (Figure 1).

In the assembly of the boxes, TDR probes with 0.20-m rods were placed in a continuous manner in a single central axis for the estimates of moisture (θ) and electrical conductivity (EC) of the soil.

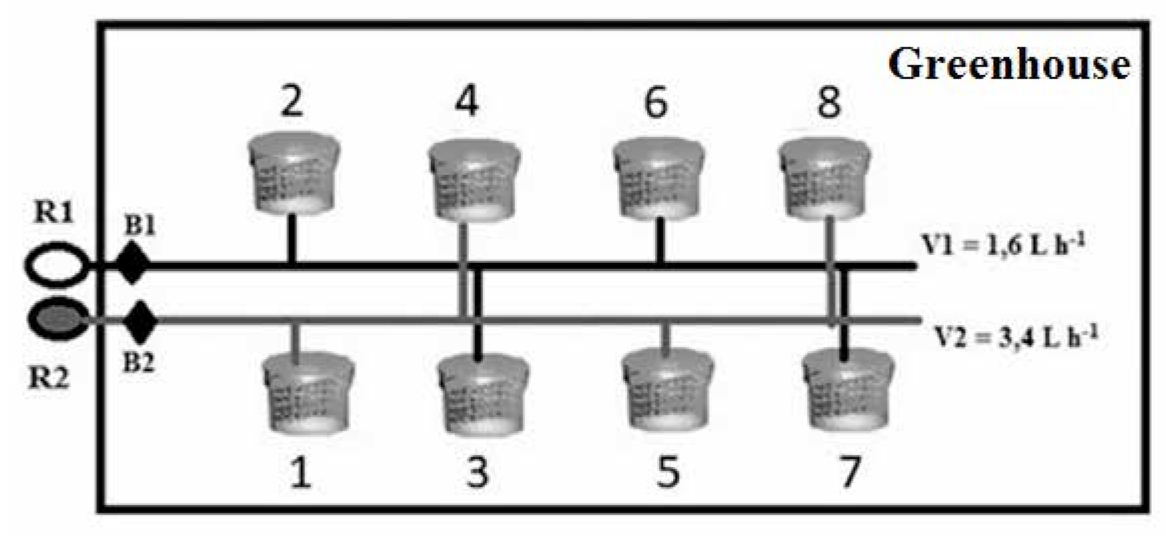

Figure 1. Layout of the boxes and their respective irrigation ways (Ri – reservoirs; Bi – hydraulic pump; Vi – Water application rate).

The probes were inserted in the horizontal position together with the soil, forming a net of 20 probes per box, as it can be seen in Figure 2.

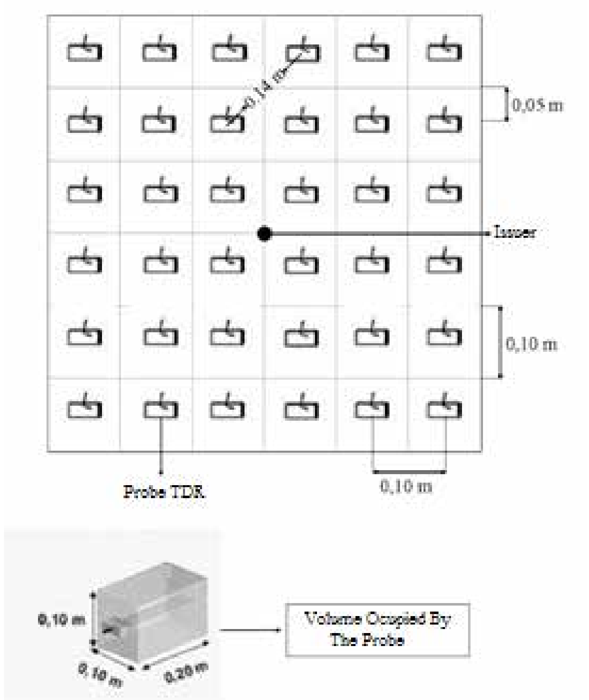

Figure 2. Distribution of TDR probes and volume per probe in the container.

The soil used in the experiment belongs to the Quarzarenic Neosol group. It was collected from the topsoil (0-0.30 m) in the region of Leme, located in the following geographical coordinates: latitude 22º11’08” S and longitude 47º23’25”W, at 619 m above sea level.

For determination of a physical analysis of the soil, non-deformed samples were removed in volumetric rings at 0-0.15 m and 0.15-0.30 m depths. The samples were taken to the Laboratory of Soil Physics and Water Quality at the university and the analysis results are shown in Table 1. During the accommodation of the soil in the boxes, we sought to approximate the density of the soil to that obtained through physical analysis.

The automatic subsurface drip irrigation system was installed in all boxes to irrigate the sugarcane crop. Irrigation was divided into two sectors (one for each flow used in the experiment), which were controlled by solenoid valves, therefore allowing to automatically activate the application of the water depth as a function of the established irrigation management.

The drippers used in the study were of the Irrigaplan[1] brand Drip Plan model, self-compensating, and buried at 0.30 m from the soil surface. Irrigation was managed so that the containers numbered two, three, six and seven received a flow rate of 1.6 L h^{-1} (T1) and the containers numbered as one, four, five and eight received a flow rate of 3.4 L h^{-1} (T2), therefore,

1 - Trademark references do not constitute endorsement by the authors.

Table 1. Soil physical analysis at the 0-0.15 and 0.15-0.30-m depths.

Samples	Particle size (%)			Porosity (%)			Density (g cm^{-3})	
Depth (m)	Clay	Sand	Silt	Micro	Macro	Total	Soil	Particle
0-0.15	6.0	91.0	3.0	10.1	29.1	39.2	1.66	2.78
0.15-0.30	7.0	92.0	1.0	8.3	29.1	37.4	1.68	2.70

distributed in an alterned manner in the greenhouse (Figure 1).

The sugarcane (*Saccharum* spp) seedlings used were of the cultivar RB 845210, prepared in nurseries at CCA - UFSCar and, later, transplanted to the boxes. Four sugarcane seedlings were transplanted into each box, totaling 16 seedlings per used flow (Figure 3). The seedlings were positioned at 0.25 m in depth, remaining at a distance of 0.05 m above the dripper.

Figure 3. Sugar cane seedlings transplanted to the containers with soil.

The probes used in the sugarcane were built at the Soil Pollution Laboratory at CCA-UFSCar, and were made using stainless steel rods with 1.6 mm in diameter. These rods were cut 70 mm long and were welded on a coaxial cable, the other end of which was inserted a BNC connector. After welding the rods, they were inserted into a silicone mold with a wooden support, where the mold was filled with epoxy resin whose function is to form a block for the support structure of the probes (PAVÃO et al., 2017).

Four months after transplanting, three of the four sugarcane stalks were selected, per box, for insertion of the probes. The probes were inserted perpendicularly to the stems on adhesive tape, to reduce pressure and, consequently, to soothe injuries to plants. Thus, there were a total of 24 probes, 12 per treatment (Figure 4).

Figure 4. Installation of the probe in the sugarcane stalk and detail of the tape used to reduce the pressure and possible damage to the plant.

Monitoring of soil moisture ()and electrical conductivity (EC) was performed using the TDR100 Reflectometer (Campbell Scientific4) using plates with SDMX-50 multiplexing channels, which analyze automatically the electromagnetic signal by means of a data collector (CR1000-Datalogger-

Campbell Scientific[5]). The software TDR-Lab (reading the probes in plants) and PCTDR (reading the probes in the soil) were used for interpretation and analysis of the collected data. The readings were taken on consecutive days for five months.

The equations described below were used to estimate soil moisture and EC (BIZARI et al., 2014).

$$\theta_{TDR} = -0.0007\mathrm{Ka}^2 + 0.036 * \mathrm{Ka} - 0.0403 \quad (1)$$

$$\mathrm{EC}_{\mathrm{Paste}} = 1.1471 * \theta_{TDR} + 1.5191 * \mathrm{CE}_{\mathrm{TDR}} + 0.041 \quad (2)$$

In which,

θ_{TDR} = Volumetric moisture (m^3 m^{-3});

Ka = apparent dielectric constant (dimensionless);

CE_{Paste} = electrical conductivity of the saturated paste (dS m^{-1}); and

CE_{TDR} = apparent electric conductivity (dS m^{-1}).

For the water content in the stem of the plants, Equation 3 of TOPP et al. (1980) was firstly used.

$$\theta_{TDR} = -5.3(10^{-2}) + 2.92(10^{-2})\mathrm{Ka} - 5.5(10^{-4})\mathrm{Ka}^2 + 4.3(10^{-6})\mathrm{Ka}^3 \quad (3)$$

Nevertheless, according to WULLSCHELEGER et al. (1996), it would be doubtful to think that a curve developed for soils could accurately estimate the water content of living tissues. For this reason, the equation of WULLSCHELEGER et al. (1996) was used to obtain the plant moisture values, θ_p (Equation 4).

$$\theta_p = -0.251 + 0.0466\mathrm{Ka} - 0.000493\mathrm{Ka}^2 \quad (4)$$

Irrigation management was carried out on the basis of the data collected daily using the TDR technique, thus maintaining soil moisture in the area of the root system at field capacity (0.26 m^3 m^{-3}) and avoiding water stress on plants. The TDR provides the apparent dielectric constant (Ka) of the soil, which is replaced in Equation 1, obtained with the calibration for this soil. Irrigation depth was calculated (Equation 5) using the average soil moisture of each treatment. Irrigation management was carried out separately for each treatment.

$$L_{LI} = ((\theta_{CC} - \theta_{TDR})p_{ef})1000 \quad (5)$$

In which,

L_{LI} = irrigation net depth (mm)

θ_{CC} = soil moisture at field capacity (m^3 m^{-3});

θ_{TDR} = achieved soil moisture (m^3 m^{-3}); and

p_{ef} = effective root depth.

Nutrient amount via fertirrigation were determined from the thorough chemical analysis of the soil, which was carried out at the Soil Fertility Laboratory at CCA-UFSCar, according to the recommendations of Technical Bulletin 100 (RAIJ et al., 1997). Fertirrigation was split into six applications during the trial period, at 15-day intervals, according to the methodology used by DALRI et al. (2008). For the application of fertilizer in each treatment, an injection pump installed outside the greenhouse was used.

Linear regressions and R^2 determination coefficients were used to assess the fit of the equations obtained in the study in monitoring the xylemic sap content and the available water in the soil.

RESULTS AND DISCUSSION

A linear regression was used to visually represent the relationship between the volumetric moisture variables in the soil (x) and in the stem (y) and, regression line equations are shown for the different treatments in Figure 5. It was observed from the determination coefficient R^2 a weak relationship between the observed values, that is, the values of R^2 were 0.17 and 0.32 for T1 and T2, respectively. This weak relationship points to the physiological complexity of the plants, added to the need to improve the technique regarding the miniaturization of the probes and the use of software more sensitive to them and to more complex media such as plant tissues.

The determination coefficient R^2 was obtained using the calibration of WULLSCHELEGER et al. (1996), with the values 0.33 and 0.36 for T1 and T2, respectively (Figure 6).

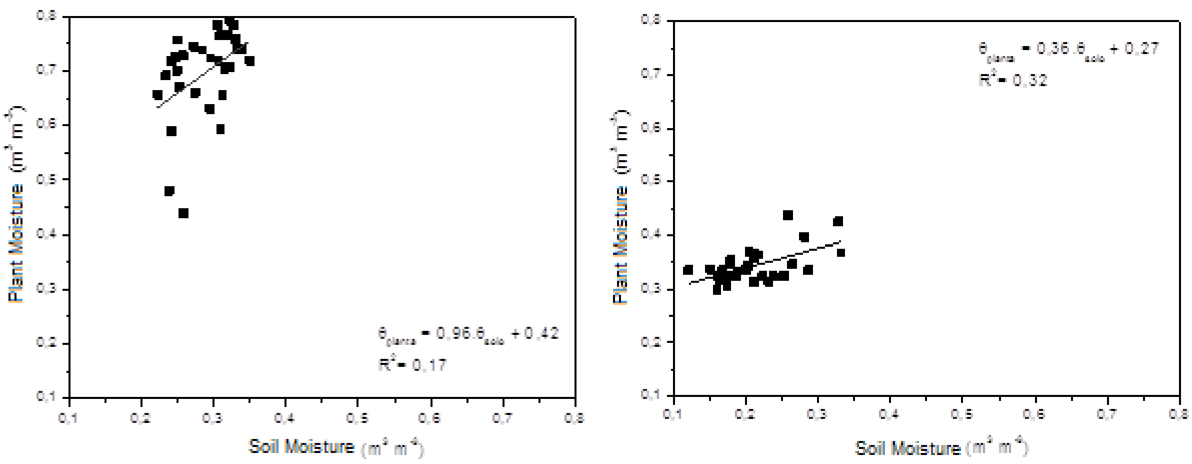

Figure 5. Linear regression between values of θ of the stem using the equation of TOPP et al. (1980), and of the soil to T1 (on the left) and T2 (on the right).

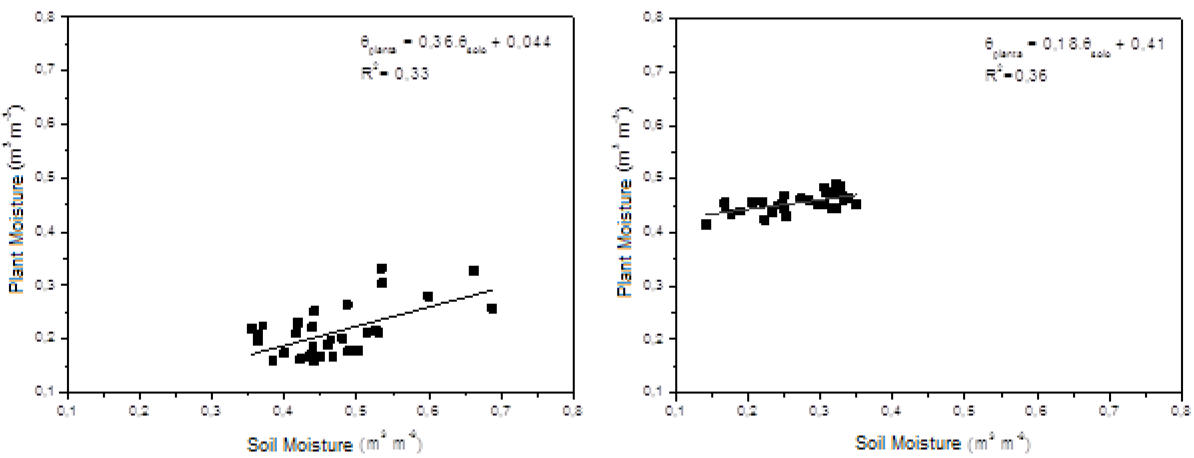

Figure 6. Linear regression of θ of the stem using the equation of WULLSCHELEGER et al. (1996), and of the soil for T1 (on the left) and T2 (on the right).

Plants that received a 3.4 L h^{-1}-flow showed the best adjustments. In complex botanic systems, such as the plant, the determination coefficients obtained become representative. According to BURSSENS et al. (2000), the low water potential may stimulate adaptive reactions that enable plants to survive in short periods of water stress. For this reason, plants that received the same water depth in less time, that is, irrigated with the highest flow (T2) had a better response.

In the soil, the water content becomes lower and lower as water deficiency increases, and water absorption by plants decreases because the cellular water potential is greater than the water potential of the soil. Thus, the osmotic adjustment does not occur due to the increase in the concentration of solutes during dehydration neither to the decrease in cell volume, but due to the biosynthesis of solutes compatible with water (COSTA, 2001). This phenomenon was responsible for raising the flow internally in the plant to the point of increasing the sensitivity of the TDR technique.

A calibration was done to estimate the moisture in plants with stems of smaller diameters, with the values of the dielectric constant obtained from it. This calibration was elaborated from the soil moisture data sets (θ) and dielectric constant (Ka) of the plant, resulting in Equation 6.

$$\theta plant = 0.0106 * Ka - 0.067, R^2 = 0.44 \quad (6)$$

The average electrical conductivity showed an increase in both media, plant and soil, with fertirrigation. This was observed in two fertirrigation applications carried out: in T1 on June 2nd (Figure 7), and in T2, on June 11th (Figure 8).

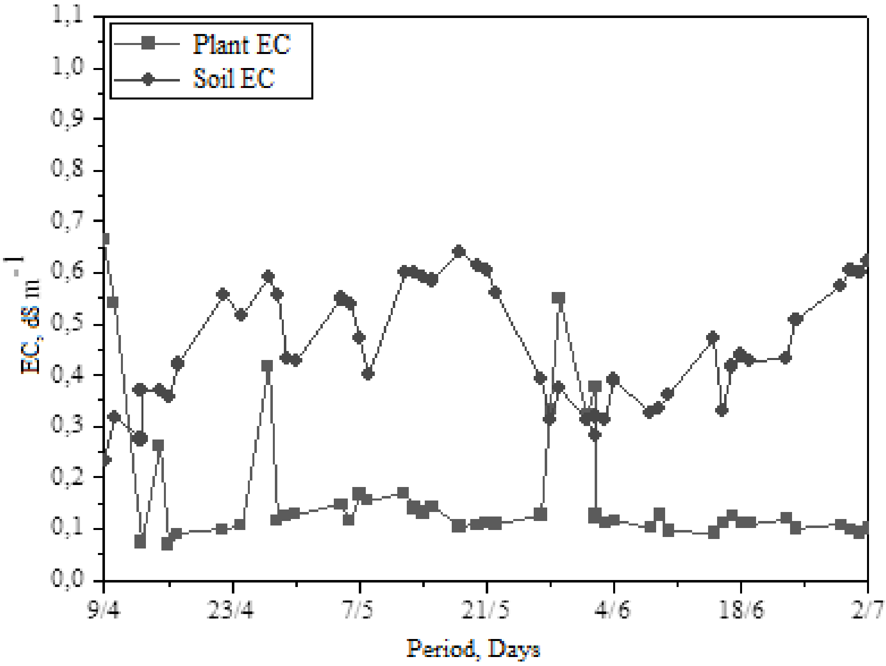

Figure 7. Electric conductivity (EC) variation in T1 after fertirrigation.

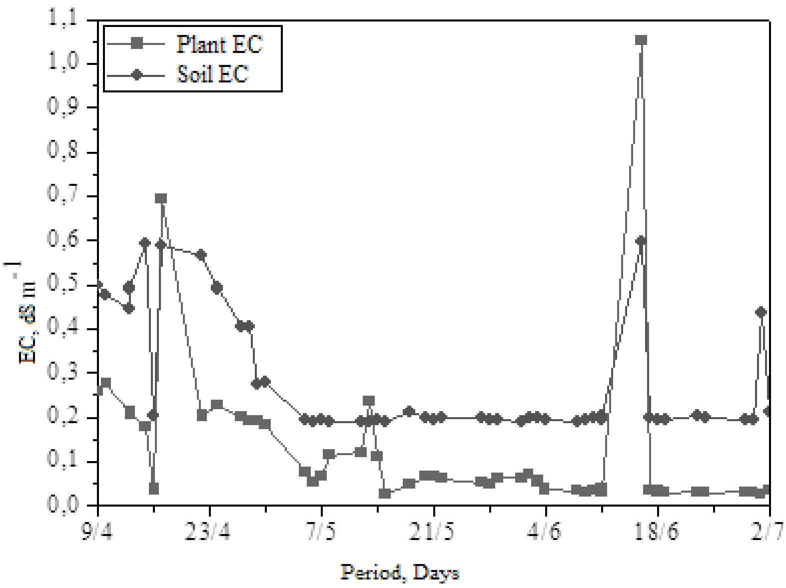

Figure 8. Electric conductivity (EC) variation in T2 after fertirrigation.

Both figures (7 and 8) show the rise in electrical conductivity in the plants when fertirrigation was performed, due to the rapid absorption of the solution applied to the soil by the sugarcane. Also, it is possible to observe that the increase in electrical conductivity was better evidenced for T2 (Figure 8), whose flow of solution application was higher.

The results observed in the study relating the two media (soil and plant), based on one variable, in a culture of economic interest, were important because it was observed that there is a weak relationship between the media even with some difficulties found in the performance. These observations lead us to invest in further studies, since the technique of monitoring xylem sap through TDR has potential for application in irrigation management in real time, and it may provide information that can be used to assist in the best possible decisions, within the conditions of uncertainty.

CONCLUSION

- It is concluded from this study that there is a weak relation between moisture in the xylemic content and the soil moisture in the sugarcane crop. The treatment with flow rate of 3.4 L h^{-1} showed a greater correlation between water content in the soil and in the plant, therefore, it obtained a better response in xylem sap monitoring.

ACKNOWLEDGEMENTS

Thanks to Foundation for Research Support of the State of São Paulo (FAPESP) and to National Council of Scientific and Technological Development (CNPq), for granting the scholarships (FAPESP Process 2014/20204-2 and CNPq Process 307042/2015-4).

REFERENCES

BIZARI, D.R.; GRECCO, K.L.; OLIVEIRA, P.L.; QUERIDO, C. M.; SOUZA, C.F. Soil solution distribution under subsurface drip fertigation determined using TDR technique. Revista Brasileira de Agricultura Irrigada, Fortaleza, v.8, n.2, p.139-146, 2014.

BURSSENS, S.; HIMANEN, K.; VAN de COTTE, B.; BEECKMAN, T.; VAN MONTAGU M.; VERBRUGEN, N. Expression of cell cycle regulatory genes and morphological alternations in response to salt stress in Arabidopsis thaliana. Planta, Berlin, v.211, n.5, p.632-640, 2000.

CHEAVEGATTI-GIANOTTO, A.; ABREU, H.M. C.; ARRUDA, P.; FILHO, J.C.B.; BURNQUIST, W.L.; CRESTE, S.; CIERO, L.; FERRO J.A.; FIGUEIRA, A.V.O.F.; FILGUEIRAS, T.S.; GUZZP, E.C.; HOFFMANN H.P.; LANDELL, M.G.A.; MACEDO, N.; MATSUOKA, S.; REINACH, F.C.; ROMANO E.; SILVA W.J.; FILHO, M.C.S.; ULIAN, E.C. Sugarcane (*Saccharum* X *officinarum*): A Reference Study for the Regulation of Genetically Modified Cultivars in Brazil. Tropical Plant Biology, Jaboticabal, v.4, n.1, p.62-89, 2011.

COSTA, A.R. As relações hídricas das plantas vasculares. Evora: Universidade de Évora, 2001, 90p.

DALRI, A.B.; CRUZ, R.L.; GARCIA, C.J.B.; DUENHAS, L.H. Irrigação por gotejamento subsuperficial na produção e qualidade de cana-de-açúcar. Irriga, Botucatu, v.13, p.1-11, 2008.

FATÁS, E.; VICENTE, J.; LATORRE, B. TDR-LAB 2.0 Improved TDR Software for soil water content and electrical conductivity measurements. Procedia Environmental Sciences, Amsterdam, v.19, p.430-483, 2013.

LOPES, M.A.; CONTINI, E. Agricultura, Sustentabilidade e Tecnologia. Agroanalysis, Rio de Janeiro, v.2012, n.2, p.28-34, 2012.

PANDEY, G.; THOSTENSON, E.T.; HEIDER, D. Electric time domain reflectometry sensors for non-invasive structural health monitoring of glass fiber composites. Progress in Electromagnetics Research, Illinois, v.137, p.551–564, 2013.

PAVÃO, G.C.; SOUZA, C.F.; BACALHAU, F.B.; MENDONCA, T.G.; GRECCO, K.L. Avaliação da técnica da TDR no monitoramento de solução xilemática em cana-de-açúcar. Irriga, Botucatu, v.1, p.144-150, 2014.

PAVÃO, G.C.; SIMIONE, J.R.; SOUZA, C.F. Construção de sondas TDR e avaliação em diferentes softwares de aplicação técnica. Engenharia na Agricultura, Viçosa, v.25, p.283-289, 2017.

RAIJ, B. van; CANTARELLA, H.; QUAGGIO, J.A.; FURLANI, A.M.C. Recomendações de Adubação e Calagem para o Estado de São Paulo. 2 ed. rev. ampl. Campinas: Instituto Agronômico

& Fundação IAC, 1997. 285p. (Boletim Técnico, 100)

SONCELA, R.; SAMPAIO, S.C.; BOAS, M.V.A.; TAVARES, M.H.F.; SMANHOTTO, A. Construction and calibration of TDR probes for volumetric water content estimation in a Distroferric Red Latosol. Engenharia Agrícola, Jaboticabal, v.33, n.5, 2013.

SOUZA, C.F.; PIRES, R.C.M.; MIRANDA, D.; VARALLO, A.C.T. Calibração de sonda FDR e TDR para a estimativa da umidade em dois tipos de solo. Irriga, Botucatu, v.18, p.597-606, 2013.

TOPP, G.C.; DAVIS, J.L.; ANNAM, A.P. Eletromagnetic determination of soil-water content: measurement in coaxial transmission lines. Water Resources Research, Washington, v.16, p.574-582, 1980.

WULLSCHELEGER, S.D.; HANSON, P.J.; TODD, D.E. Measuring stem water content in four deciduous hardwoods with a time-domain reflectometer. Tree Physiology, Oxford, v.16, p.809-815, 1996.