Root growth of sugarcane irrigated with wastewater through subsurface drip system

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Abstract: The use of wastewater in agriculture is an alternative to provide water and nutrients for plants. However, root system development can be affected by water quality and depth of wastewater applied. The objective of this study was to evaluate the sugarcane root system growth using a minirhizotron in a field irrigated with treated sewage effluent and freshwater by subsurface drip irrigation. The treatments tested were two drip line installation depths (0.2 and 0.4 m); two water sources (treated sewage effluent and freshwater) and non-irrigated plots as control. The experiment was a randomized block design with a $2\times2+1$ factorial, with three replications. The root system evaluation (root length and spatial distribution) was performed using a minirhizotron with an access tube buried in the soil profile and installed on a 45 degree angle. The soil moisture was determined using the time-domain reflectometry technique. The lowest moisture on the soil surface resulted in the highest root length density (0.18 cm cm^{-2}) at the non-irrigated plots (p>0.05). The application of treated sewage effluent and the installation depth of drip line did not change the root length of sugarcane in first ratoon (p>0.05). Eighty percent of the root system was accumulated from the soil surface to 0.45 m.

Keywords: root scanner, minirhizotron, drip irrigation, time domain reflectometry (TDR), *Saccharum officinarum* L.

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1 Introduction

The root system is responsible for plant support and water and nutrient uptake. The processes occurring in the soil profile, especially root distribution and growth, should be considered to better understand the sugarcane development (Vasconcelos and Dinardo-Miranda, 2011). However, root system evaluation is laborious and can be influenced by the variability of physical, chemical and biological soil properties, water management and cultural practices, which may mask root quantification (Vasconcelos et al., 2003).

The root system is an important component in the irrigation management, because the soil water content influences the root system depth (Allen et al., 1998). When obtaining information about the effective roots system some factors should be considered, such as precision, measured parameters, research objectives, culture and the experimental growing conditions (Vasconcelos et al., 2003). In addition, fast, non-destructible, labor-saving methods allowing periodic observations should be preferable in relation to trench opening method or auger use. Such characteristics can be obtained by minirhizotron, which is based on the collection of root images using transparent tubes installed in the soil profile during plant growth. After the installation of an access pipe, the information about root system is taken without impact on plant stand (Dilustro et

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al., 2002), enabling the observation of the plant growing cycles (Wallander et al., 2013).

Considering the increased water demand by different sectors of society, especially for agriculture, it is necessary to use alternative water sources, such as treated sewage effluent (TSE). The application of TSE in irrigated agriculture have the potential to minimize water scarcity and environmental degradation, increasing water resources availability and water use efficiency (Sandri et al., 2009).

Among the available irrigation methods, subsurface drip irrigation is recommended for applying TSE (Puig-Bargués et al., 2010). This system applies water directly into the root zone, which increases water use efficiency and minimizes the risk of operator contamination due to sewage use (Cararo and Botrel, 2007).

The scientific knowledge about the interaction sewage-soil-plant still scarce. Studies related to the quantity and distribution of the root system in the soil profile in tropical and subtropical areas are essential to assess the rational and sustainable use of this residue, defining the effective depth of the root system and thus orienting irrigators.

The objective of this study was to evaluate the sugarcane root system growth using a minirhizotron in a field irrigated with treated sewage effluent by subsurface drip irrigation.

2 Materials and methods

2.1 Location and environmental conditions

The study was performed at the University of Campinas, School of Agricultural Engineering (22°53’S, 47°05’W, and altitude of 620 m), Campinas, SP, Brazil in an Oxisol (Embrapa, 2013). The location is a transition between Cwa and Cfa according to the Köppen-Geiger classification (Peel et al., 2007), with average annual rainfall of 1,424 mm and temperature of 22.4℃ (Cepagri, 2013).

Figure 1 indicates the reference evapotranspiration using the Penman-Monteith method, the average monthly rainfall, the irrigation levels for irrigated treatments (T2, T3, T4 and T5) and the average air temperature observed during the experiment, according to Cepagri (2013). Supplemental irrigation was applied to compensate the irregular rainfall and maintain soil moisture near to field capacity.

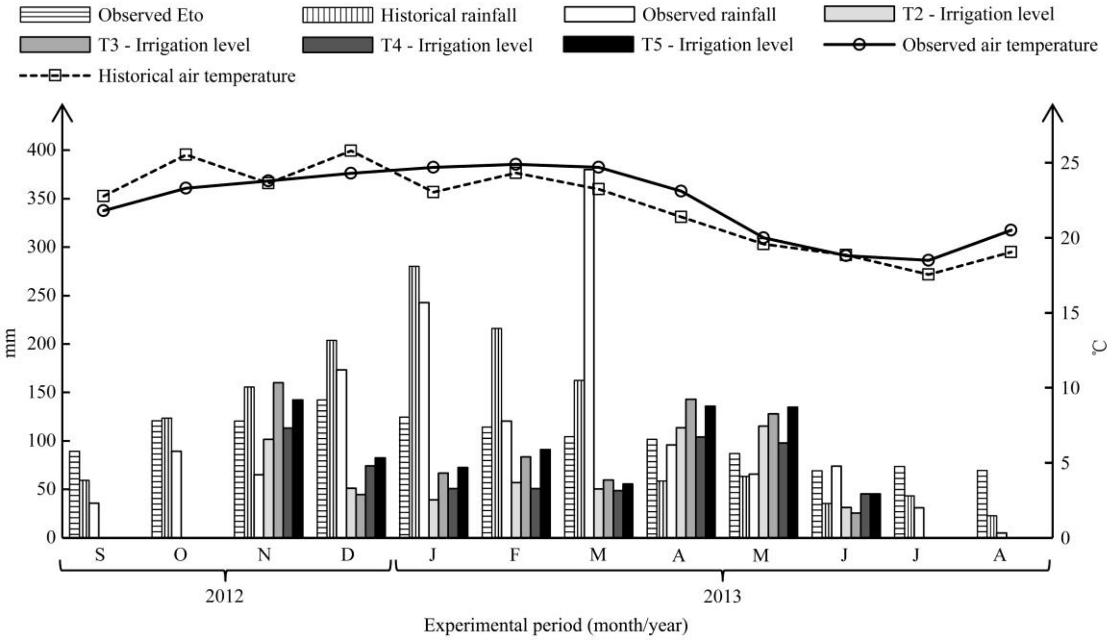


Figure 1 Reference evapotranspiration (observed ETo), monthly and historical rainfall, water applied by the treatments (T2, T3, T4 and T5) and the monthly mean air temperature observed and historical, according to Cepagri (2013).

2.2 Treatments and experimental design

We tested two drip line installation depths (0.2 and 0.4 m), two water sources (freshwater and TSE), and a control (non-irrigated plots with conventional fertilization), totaling five treatments with three replications. Treatments: (T1) non-irrigated plots, (T2)

TSE applied to 0.20 m depth and (T3) 0.40 m, (T4) irrigation with freshwater to 0.20 m depth and to (T5) 0.40 m. The experimental design was complete randomized blocks arranged on a $2 \times 2 + 1$ factorial.

Sugarcane var. RB867515 was planted in May 2011 by distributing 15 to 18 buds per linear meter, with planting depth of 0.30 m, grown in three double rows per experimental plot, considering the two outermost lines as borders with the center one as the main line. Spacing between the centers of the double rows (consisting of two rows spaced at 0.4 m apart) was 1.8 m. The area of each experimental plot was 97.2 m^2 (5.4 m × 18 m), totaling 2430 m^2 for the entire experiment. Plant assessments were conducted in the first sugarcane ratoon from September/2012 and August/2013.

2.3 Experimental conditions

We used a subsurface drip line (Dripnet PC AS; Netafim, Tel Aviv, Israel) with water flow of 1.0 L h^{-1} (spaced every 0.55 m) for applying freshwater and 1.6 L h^{-1} (spaced every 0.65 m) for applying TSE. The spacing difference between the emitters was due to results from a preliminary study performed at the same site (Elaiuy et al., 2015). There were no differences between the flow rates of 1.0 and 1.6 L h^{-1} on wet bulb dimensions from application of two water qualities and discharge between drippers in sugarcane.

Freshwater was collected in a superficial reservoir located near the experimental field and the TSE from a treatment station located on campus. Sewage from the School of Agricultural Engineering was treated by a compartmentalized anaerobic reactor and wetland system (Zanella, 2008). Freshwater and TSE samples collected after the irrigation water was filtered on a sand filter (FA3; Hidro Solo/Pluvitec, Maceió, Alagoas, Brazil), every two months to characterization of both in relation to use in irrigation (Ayers and Westcot, 1999). The analyses were performed as recommended by the Standard Methods for the Examination of Water and Wastewater (APHA, 2012), and by the United States Environmental Protection Agency (USEPA, 2013). Data is available in Table 1.

The irrigation management was performed by soil water balance. The soil volumetric water content was estimated and the water volume was applied to reach the soil field capacity (FC) of 0.35 m^3 m^{-3} obtained by the Richards pressure chamber method (Camargo et al., 2009). The soil profile used in the calculation of the irrigation water amount was between 0.0 and 0.6 m to the tubes installed at 0.2 m depth and from 0.2 to 0.8 m to the drip line installed at 0.4 m depth.

Table 1 Water quality applied by irrigation during rain (October to March) and dry season (April to August)

Season	Water sources	EC[(a)], dS m^{-1}	SAR[(b)], mmol L^{-1}	Sodium	Chloride	Boron	pH
				mg L^{-1}			
Rainy	Freshwater	0.07	0.30	2.20	0.03	<0.001	7.33
	TSE[(c)]	0.99	4.46	56.36	0.02	0.31	7.70
Dry	Freshwater	0.06	0.27	2.20	<0.01	<0.001	7.23
	TSE	1.24	5.66	76.70	0.01	0.20	7.21

Note: (a) EC=Electric Conductivity; (b) SAR=Sodium Adsorption Ratio; (c) TSE= Treated Sewage Effluent.

2.4 Measurements

The soil water content was measured by time domain reflectometry (TDR) using a TDR-100 sensor (Campbell Scientific, Logan, Utah, United States). Five probe rods of 0.2 m were installed vertically in the ground up to 1 m. TDR probes were installed horizontally at 0.1 m depth for the overtime monitoring. Soil moisture sampling occurred 1 h before each irrigation, using a soil-specific equation to estimate the soil water content (Equation 1) (Souza et al., 2001).

$$\theta = 3\times10^{-5}Ka^3 - 0.0017\mathrm{Ka}^2 + 0.0415\mathrm{Ka} - 0.0603 \quad (R^2 = 0.98) \tag{1}$$

where, θ = soil volumetric water content (m^3 m^{-3}); Ka = apparent dielectric constant (unitless).

Disturbed and undisturbed soil samples were obtained before the study start and after the harvest of first ratoon sugarcane to determine the physical and chemical soil properties. Four trenches were randomly dug in the experimental area before planting. At the end of the first ratoon, three trenches per treatment were opened to collect samples from 0-0.2; 0.2-0.4; 0.4-0.6; and 0.6-0.8 m depth.

In the final sampling, each trench was opened 0.1 m away from the crop row for root system evaluation. The methodology proposed by Camargo et al. (2009) was used for chemical analysis ($CaCl_2$, pH = extractors; P = Resin; K = Mehlich 1:10; Al, Ca and Mg = KCl 1N 1:10). Bulk density, porosity (total, macro and micro), texture and soil water retention curve was determined as described in Embrapa (2011). The water retention curve was adjusted accordingly to Van Genuchten model (Genuchten, 1980).

The fertilization was performed in all treatments with application of 120, 40 and 80 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. A single topdressing application was performed in the T1 treatment, while the fertigated treatments received fertilization once a week immediately after planting. Therefore, two irrigations and one fertigation were performed weekly, except during the rainy season, when irrigation was suspended and fertigation maintained.

2.4.1 Evaluation of the root system

Root images were taken using a root imager (CI-600; CID Bio-Science, Camas, Washington, United States) to monitor root growth during the crop cycle. Tubes made of transparent acrylic (64 mm internal diameter × 70 mm outer diameter × 1050 mm length) were installed in all replicated treatments to take the root images. Tubes were installed in parallel to the sugarcane planting line (0.1 m away) and on a 45-degree angle to the soil surface (as recommended by Johnson et al., 2001). Tubes installed vertically may overestimate the root length density values in deeper layers (Linsenmeier et al., 2010). The installation of the tubes was performed with a ED-43 semi-mechanized post hole digger (Kawashima, Chang-hua Hsien, Taiwan) using a 75-mm diameter drill and a template to guide the angle of tube insertion. The diameter of the drill was chosen to maintain an 8-mm distance between the pipe outer wall and the soil. According to the root imager manufacturer, the sensor does not capture the light reflected by the soil-root set at higher distances.

The tube lower extremity was sealed with a plexiglass cover and the upper extremity with a removable black plastic cover, facilitating the scanner insertion and promoting sunlight and rainfall protection. The root monitoring occurred on two occasions: (1) late growth stage of the stems - 189 days after harvest; and (2) maturation - 252 days after harvest. As the tubes were installed diagonally, the collected images represented the layers from 0-0.15, 0.15-0.3, 0.3-0.45, and 0.45-0.6 m depth. Each image measured 21.59 × 19.56 cm (= 422.30 cm^2). This image was the same as the perimeter of the tube and the length of the scanner and reader. The tiller number count was performed above the tube (1 m on the soil surface).

The images were processed using the CI-690 RootSnap software (CID Bio-Science, Inc., Camas, Washington, EUA) for characterization of the root system and the root length density parameters (RLD) and distribution. The RLD was calculated by the root length ratio observed on each layer and the area of each image. The percent distribution was calculated as the total length up to 0.6 m deep and represents the contribution of each layer to the total RLD observed. The percent distribution is important because it shows how RLD is distributed in the soil layers, allowing the observation in which layer we found higher RLD values. It also allows to determine the effective rooting depth (ERD) and it facilitates the comparison with other studies (Ohashi et al., 2015).

2.4.2 Evaluation of the sugarcane production and quality

At the end of the sugarcane cycle (348 days after harvest), tillers were sampled over 1.0 m in the effective line to estimate the stem production (ESP), the theoretical yield of recoverable sugar (Equation (2)) and the sugarcane technological parameters such as: soluble solids content of the juice (SSC), apparent sucrose of the juice (Pol), purity apparent of the juice (Purity), content of fiber (fiber), total recoverable sugar (TRS), reducing sugars (RS) and theoretical yield of recoverable sugar (TYRS) as described by Consecana (2006).

$$TYRS = (TRS \times ESP) * 0.001 \tag{2}$$

where, $TYRS$ = theoretical yield of recoverable sugar (t ha^{-1}); TRS = total recoverable sugar (kg t^{-1}); ESP = estimate of stem production (t ha^{-1}).

2.5 Statistical analysis

The data were subjected to analysis of variance by F test and mean comparison test by Tukey at 5% probability using the software SISVAR (Federal University of Lavras, Lavras, Minas Gerais, Brazil).

3 Results and discussion

3.1 Physical and chemical properties

Significant effects were observed for the soil bulk density (BD) at a depth of 0.2-0.6 m (*p*>0.05, Table 2 and 3), and potential acidity (H + Al) in the layer of 0.2-0.4 m (*p*>0.05, Table 2). The BD values were 5.4% lower at the end of the first ratoon (1.4 and 1.33 Mg/m for the layers 0.2-0.4 and 0.4-0.6 m, respectively) compared to the values obtained before the experiment implantation (1.38, 1.48, 1.36 and 1.20 for the layers 0-0.2, 0.2-0.4, 0.4-0.6 and 0.6-0.8 m, respectively). These results were mainly caused by the soil compaction of the previous years. This is due to the use of the minimum tillage (furrow opening for planting and installation of the drip tape) and input of agricultural machines in the experimental area for sugarcane harvest. According to Demattê (2004), the excessive traffic of machines can increase the soil BD.

Table 2 Physical properties and chemical analysis of two soil layers at the end of the first ratoon of sugarcane, Campinas, Brazil

Treat. layer	BD(a), Mg m^{-3}	TP(b)	MaP(c)	MiP(d)	pH	P, mg dm^{-3}	K	Ca	Mg	H+Al(e)	OM(f), %
		------- m^3 m^{-3} -------					--------- cmol$_c$ dm^{-3} ---------				
-- Layer 0-0.2 m ----------------------------------											
T1(g)	1.30	0.56	0.15	0.41	4.90	21.00	0.42	4.33	0.93	3.93	4.03
T2(h)	1.19	0.53	0.14	0.39	4.83	21.33	0.47	4.23	0.93	4.30	3.80
T3(i)	1.28	0.53	0.12	0.41	4.77	17.00	0.62	4.37	1.03	4.90	4.40
T4(j)	1.18	0.55	0.14	0.41	4.77	20.33	0.45	4.33	0.97	4.37	4.07
T5(k)	1.25	0.54	0.13	0.40	5.03	35.33	0.64	4.13	0.93	3.40	3.67
F Test	2.04^{ns}	0.22^{ns}	0.12^{ns}	0.66^{ns}	2.52^{ns}	0.71^{ns}	2.72^{ns}	0.06^{ns}	0.33^{ns}	1.56^{ns}	1.12^{ns}
CV (%)(l)	5.12	8.97	42.24	6.02	2.51	63.54	20.39	15.57	13.65	18.43	11.53
LSD(m)	0.18	0.14	0.16	0.07	0.34	41.23	0.30	1.88	0.37	2.17	1.30
-- Layer 0.2-0.4 m ----------------------------------											
T1	1.31ab(n)	0.52	0.11	0.41	4.97	6.33	0.19	3.80	0.87	3.70ab	3.27
T2	1.40a	0.52	0.09	0.43	4.90	14.33	0.24	3.90	0.83	4.00ab	3.10
T3	1.39a	0.50	0.06	0.43	4.90	12.00	0.27	3.83	0.87	4.23a	3.50
T4	1.07b	0.53	0.15	0.39	4.90	5.67	0.11	3.53	0.77	3.70ab	3.20
T5	1.40a	0.51	0.08	0.42	5.10	15.67	0.24	3.83	0.90	2.90b	3.00
F Test	7.87*	0.32^{ns}	0.97^{ns}	1.17^{ns}	2.96^{ns}	1.06^{ns}	1.19^{ns}	0.18^{ns}	0.94^{ns}	3.72*	0.90^{ns}
CV (%)	6.68	8.26	58.60	7.31	1.77	71.26	48.51	15.27	10.67	12.21	10.77
LSD	0.05	0.12	0.16	0.09	0.25	21.72	0.29	1.63	0.26	1.28	0.98

Note: (a) BD=Soil bulk density; (b) TP=Total Porosity; (c) MaP=Macroporosity; (d) MiP=Microporosity; (e) H+Al=Potential acidity; (f) OM=Organic matter; (g) T1=Non-irrigated plots; (h) T2=TSE (treated sewage effluent) applied to 0.20 m depth; (i) T3=TSE applied to 0.40 m depth; (j) T4=Freshwater applied to 0.20 m depth; (k) T5=Freshwater applied to 0.40 m depth; (l) CV=Coefficient of variation; (m) LSD=Least significant difference; (n) Distinct letters in the columns indicate significant differences according to Tukey's test (*p*>0.05); * F Test significant at p>0.05; ^{ns} F Test non-significant at *p*>0.05.

Table 3 Physical properties and chemical analysis of two layers of soil at the end of the first ratoon of sugarcane, Campinas, Brazil

Treat. layer	BD(a), Mg m^{-3}	TP(b)	MaP(c)	MiP(d)	pH	P, mg dm^{-3}	K	Ca	Mg	H+Al(e)	OM(f), %
		------- m^3 m^{-3} -------					--------- cmol$_c$ dm^{-3} ---------				
-- Layer 0.4-0.6 m ----------------------------------											
T1(g)	1.24ab(n)	0.54	0.10	0.43ab	4.97	3.67	0.20	2.60	0.73	3.63	2.53
T2(h)	1.33a	0.52	0.07	0.45a	4.90	11.67	0.09	2.80	0.73	3.73	2.47
T3(i)	1.16b	0.48	0.07	0.41 b	4.87	4.33	0.17	2.70	0.73	4.33	2.77
T4(j)	1.26ab	0.54	0.10	0.43ab	4.90	4.33	0.09	2.67	0.67	3.60	2.57
T5(k)	1.17b	0.52	0.11	0.41b	5.1	4.67	0.13	2.83	0.73	2.77	2.23
F Test	5.02*	1.87^{ns}	1.27^{ns}	7.28*	0.83^{ns}	1.70^{ns}	0.77^{ns}	0.12^{ns}	0.35^{ns}	1.43^{ns}	1.19^{ns}
CV (%)(l)	4.32	5.67	32.12	2.21	3.59	77.32	69.53	18.05	12.16	22.44	12.13
LSD(m)	0.15	0.08	0.08	0.03	0.50	12.51	0.26	1.39	0.25	2.29	0.86
-- Layer 0.6-0.8 m ----------------------------------											
T1	1.14	0.55	0.14	0.41	5.10	3.00	0.20	2.40	0.77	3.23	1.97
T2	1.18	0.50	0.09	0.41	4.90	3.67	0.09	2.40	0.73	3.57	1.97
T3	1.13	0.55	0.13	0.42	4.80	3.67	0.12	2.13	0.67	4.67	2.07
T4	1.17	0.54	0.12	0.42	4.87	3.00	0.07	2.47	0.63	3.93	2.00
T5	1.14	0.53	0.11	0.41	5.10	3.67	0.10	2.60	0.77	2.70	1.77
F Test	0.66^{ns}	0.96^{ns}	0.41^{ns}	0.35^{ns}	1.14^{ns}	0.44^{ns}	0.94^{ns}	0.38^{ns}	0.79^{ns}	1.5^{ns}	0.71^{ns}
CV (%)	3.81	7.12	40.62	4.28	4.54	27.90	80.13	20.01	16.59	28.88	11.80
LSD	0.12	0.11	0.14	0.05	0.64	2.68	0.26	1.36	0.33	2.95	0.65

Note: (a) BD=Soil bulk density; (b) TP=Total Porosity; (c) MaP=Macroporosity; (d) MiP=Microporosity; (e) H+Al=Potential acidity; (f) OM=Organic matter; (g) T1=Non-irrigated plots; (h) T2=TSE (treated sewage effluent) applied to 0.20 m depth; (i) T3=TSE applied to 0.40 m depth; (j) T4=Freshwater applied to 0.20 m depth; (k) T5=Freshwater applied to 0.40 m depth; (l) CV=Coefficient of variation; (m) LSD=Least significant difference; (n) Distinct letters in the columns indicate significant differences according to Tukey's test (*p*>0.05); * F Test significant at p > 0.05; ^{ns} F Test non-significant at *p*>0.05.

3.2 Root system

There were no significance differences for root length density (RLD) between treatments evaluated (*p*>0.05, Table 4). This result indicates the EC levels verified in TSE and the greatest value of H+Al observed in T3, which differed from those observed in T5, not caused damage to sugarcane root development in the second cultivation season, allowing homogeneous growth of roots in the soil profile (Table 1).

Table 4 Root length density in four soil depth layers performed in two samplings in the first ratoon of sugarcane

Layer, m	T1$^{(a)}$	T2$^{(b)}$	T3$^{(c)}$	T4$^{(d)}$	T5$^{(e)}$	F Test	CV$^{(f)}$, %	LSD$^{(g)}$
	cm cm^{-2}							
				1st Sampling				
0-0.15	0.06	0.04	0.03	0.01	0.03	2.29^{ns}	65.85	0.07
0.15-0.30	0.01	0.03	0.01	0.01	0.02	0.69^{ns}	150.03	0.06
0.30-0.45	0.01	0.01	0.02	0.01	0.01	1.29^{ns}	65.90	0.02
0.45-0.60	0.01	0.01	0.01	0.01	0.02	3.07^{ns}	74.65	0.02
				2nd Sampling				
0-0.15	0.06	0.05	0.04	0.02	0.03	1.73^{ns}	51.07	0.06
0.15-0.30	0.05	0.02	0.02	0.01	0.02	0.74^{ns}	136.03	0.09
0.30-0.45	0.04	0.01	0.03	0.01	0.01	2.69^{ns}	90.64	0.05
0.45-0.60	0.03	0.01	0.01	0.01	0.01	1.36^{ns}	128.60	0.05

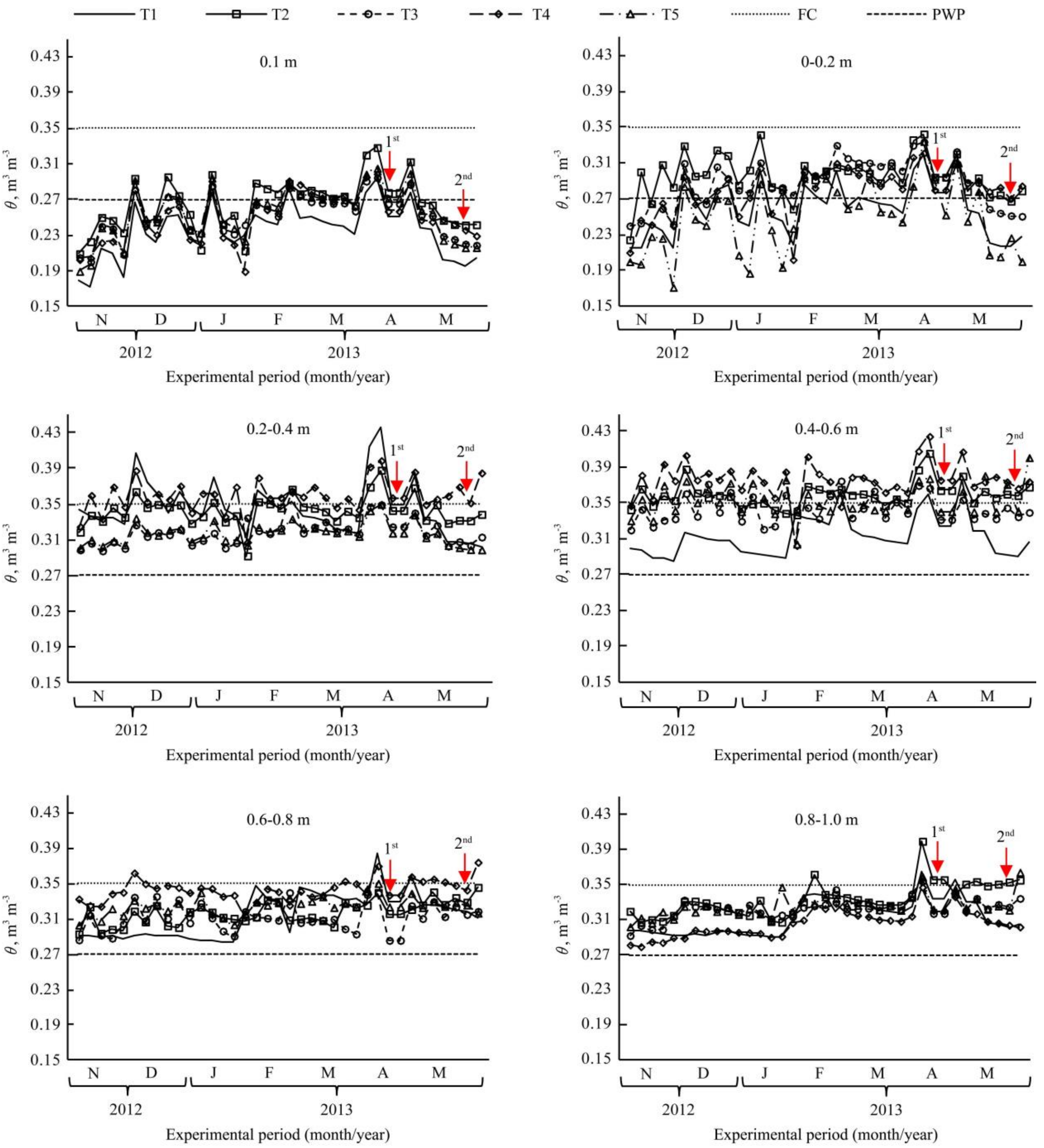
Note: (a) T1=Non-irrigated plots; (b) T2=TSE (treated sewage effluent) applied to 0.20 m depth; (c) T3=TSE applied to 0.40 m depth; (d) T4=Freshwater applied to 0.20 m depth; (e) T5=Freshwater applied to 0.40 m depth; (f) CV=Coefficient of variation; (g) LSD=Least significant difference; ^{ns} F Test non-significant at *p*>0.05; 1st: late growth stage of the stems, 189 days after harvest; and 2nd: maturity stage, 252 days after harvest.

The rainfed treatment (T1) did not differ from irrigated treatments on RLD, which may have occurred because of high rainfall (Figure 1) and soil volumetric water content (Figure 2), promoting uniform root growth (*p*>0.05, Table 4). Similar results were observed by Farias et al. (2008), who studied the sugarcane root development in irrigated and non-irrigated conditions, and the results of Sousa et al. (2013) in sugarcane irrigated with sewage and non-irrigated. Furthermore, there was no RLD effect at different depths of installation of the drip line (0.2 and 0.4 m) (Table 4). Kamara et al. (1991), evaluating the effect of drip installation depth not observed effects in the cotton root development in areas with high water depths.

According to Boni et al. (2008), the ERD is the depth in which more than 80% of the roots are concentrated, and all treatments showed ERD up to 0.45 m in the second sampling (Figure 3). The observed results are in agreement with several studies of the sugarcane root system. Alvarez et al. (2000) found that 72% and 75% of the roots harvested with and without burning, respectively, in the first 0.4 m depth of the first ratoon; and 68% and 70%, respectively, in the second ratoon. Faroni and Trivelin (2006) found 90% of metabolically active roots between 0.0 to 0.4 m depth. Farias et al. (2008) obtained 90% and 80% of the roots in irrigated and rainfed system, respectively, in the first 0.60 m depth. Sousa et al. (2013) observed the same effective root depth (0.4 m) for rainfed and irrigated treatment with 100% and 200% of water depth based on crop evapotranspiration (using TSE). Ohashi et al. (2015), also evaluating root growth in sugarcane crop fertigated via subsurface drip irrigation with minirhizotron, observed very similar ERD values (0.4 m), although using different sugarcane cultivars.

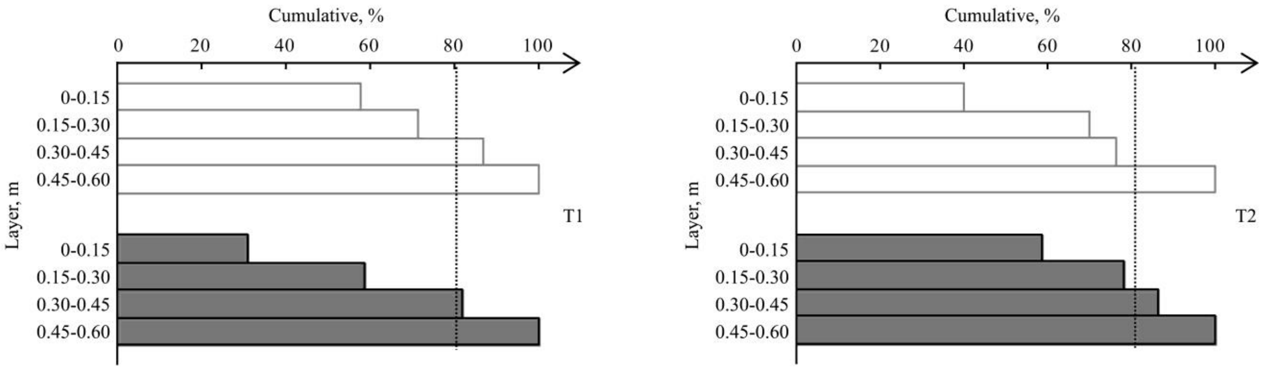
We observed different root distribution according to the sampling dates (Figure 3). T1 reduced the root distribution percentage in 0-0.15 m layer in the second sampling date, while the irrigated treatments increased the root distribution. It means that under rainfed conditions there is a tendency to increase the root distribution in deeper layers, as pointed out by Vasconcelos and Dinardo-Miranda (2011). Thus, when analyzing the same point over time has allowed to observe the effect of precipitation.

The evaluation using the minirhizotron is a non-destructive technique that allowed the continuous monitoring at the same sampling point. Hence, we could observe that root distribution varies along the crop cycle, which was also observed by Ohashi et al. (2015).



Note: Red arrows show 1st and 2nd sampling.

Figure 2 Soil volumetric water content during the first ratoon of sugarcane in six layers of soil



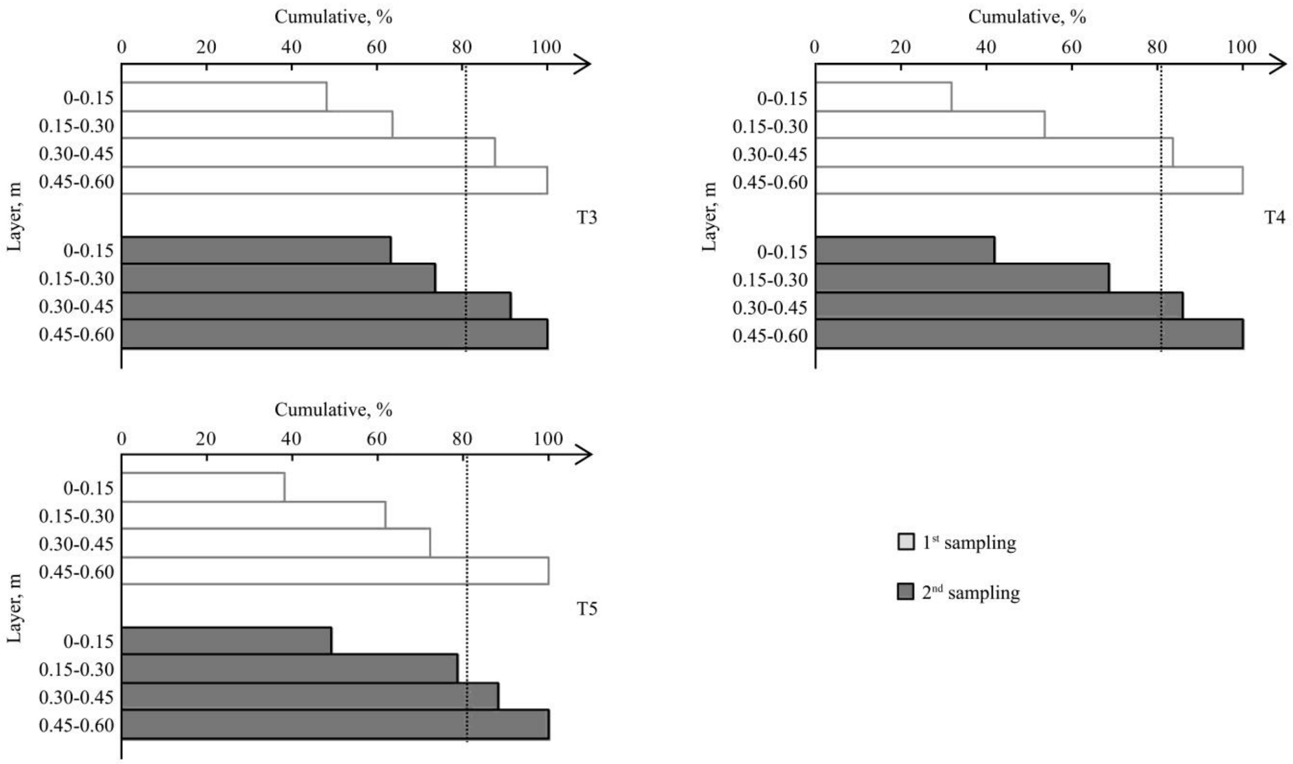
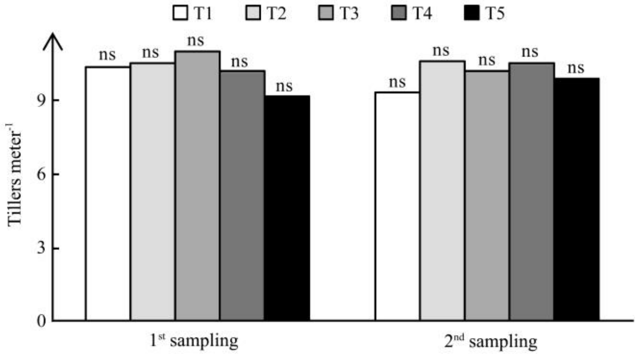


Figure 3 Cumulative percentage of roots in the soil profile (0-0.6 m) in the 1st ratoon of sugarcane in two samplings: 1st- late growth stage of the stems (189 days after harvest); and 2nd- maturity stage (252 days after harvest)

3.3 Sugarcane quality and production

There were no differences among treatments for number of plants regardless of the sampling time, portraying the plots stand uniformity for the root system evaluation (p>0.05, Figure 4).



Note: ns= averages do not differ by Tukey test at 5% probability.

Figure 4 Number of tillers in a meter of the first ratoon sugarcane in two samplings: 1st- late growth stage of the stems (189 days after harvest); and 2nd- maturity stage (252 days after harvest)

The average stem yield obtained in the study was 211.85 t ha^{-1} (Table 5), 205.26% higher than the national average (69.40 t ha^{-1}) and 183.22% higher than the São Paulo state average (74.80 t ha^{-1}) in 2012-2013 (Conab, 2013). The TRS values were also 7.04% higher than the national average of 136 kg t^{-1} (Conab, 2013). Significant differences were observed only to ESP and TYRS parameters between treatments irrigated and non-irrigated, which is directly associated with increased in stem mass provided by the irrigation (Dalri and Cruz, 2008) and the high quality of the soil (fertility and water retention). In a study about subsurface drip irrigation with fertigation in São Paulo/Brazil into the first ratoon in three different varieties of sugarcane, Gava et al. (2011) observed 24% higher stem production and 23% higher sugar in fertigated cultivation compared to without irrigation.

Irrigation plus fertigation (TSE or freshwater) promoted considerable gains in sugarcane production compared to non-irrigated treatments (Table 5). These results are in accordance to Dantas Neto et al. (2006), Dalri and Cruz (2008), Dalri et al. (2008), Andrade Jr et al. (2012), Barbosa et al. (2012) and Quintana et al. (2012). Thus, the use of irrigation may be determinant to maintain sustainable production for several cycles without the need to renew the planted area with new plantations in short periods, as does not occur in non-irrigated crops.

Table 5 Sugarcane quality and production to five treatments in the first ratoon of sugarcane

Treatments	SSC$^{(a)}$, %	Pol$^{(b)}$, %	Purity$^{(c)}$, %	RS$^{(d)}$, %	Fiber$^{(e)}$, %	TRS$^{(f)}$, kg t^{-1}	ESP$^{(g)}$, t ha^{-1}	TYRS$^{(h)}$, t ha^{-1}
1	18.81	16.58	88.11	0.62a$^{(i)}$	10.87	142.75	160.67b	22.91b
2	18.89	17.07	90.37	0.54a	11.01	145.92	236.07a	34.52a
3	18.84	16.88	89.53	0.57a	11.09	144.26	229.42a	33.11a
4	19.23	16.99	88.39	0.61a	10.84	146.24	221.58a	32.40a
5	19.49	17.63	90.41	0.54a	11.66	148.75	211.53a	31.41a
F test	0.52^{ns}	0.74^{ns}	3.04^{ns}	3.07*	1.08^{ns}	0.53^{ns}	6.84*	6.19*
CV(%)$^{(j)}$	4.82	5.85	1.55	8.41	6.49	4.78	12.12	13.36
LSD$^{(l)}$	1.74	1.89	2.62	0.09	1.36	13.16	48.62	7.81

Note: $^{(a)}$ SSC=Soluble solids content of the juice; $^{(b)}$ Pol=Apparent sucrose of the juice; $^{(c)}$ Purity=Purity apparent of the juice; $^{(d)}$ RS=Reducing sugars; $^{(e)}$ Fiber=Content of fiber; $^{(f)}$ TRS=Total recoverable sugar; $^{(g)}$ ESP=Estimate of stem production; $^{(h)}$ TYRS=Theoretical yield of recoverable sugar; $^{(i)}$ Distinct letters in the columns indicate significant differences according to Tukey's test (p>0.05); $^{(j)}$ CV(%)=Coefficient of variation; $^{(l)}$ LSD=Least significant difference; * F Test significant at p>0.05; ^{ns} F Test non-significant at p > 0.05.

4 Conclusions

The application of treated sewage effluent and the depth of drip line installation does not change the root length of sugarcane in the first ratoon. The majority of the root system is concentrated from the ground surface to 0.45 m (about 80%), but the distribution pattern varied along the crop cycle. Regardless of the applied water quality, the use of irrigation increased the stem productivity in 205.23% and recoverable sugar in 7.04%.

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