ROOT AND WATER DISTRIBUTION IN SOIL CULTIVATED WITH FORAGE CACTUS UNDER DIFFERENT IRRIGATION SETTINGS

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SUMMARY: The knowledge of root distribution of crops in the soil is important for irrigation management and fertilizer application. The objective of this work was to determine root and water distribution profiles in the soil cultivated with Giant forage palm under different combinations of irrigation depth and irrigation interval with saline water. The experimental design was randomized blocks with three replicates, following a 7 x 7 x 4 factorial; seven water application conditions: no irrigation; 7% of the reference evapotranspiration (ETo) with irrigation interval (II) of 15 days; 15% of the ETo with II of 7 days; 33% of the ETo with II of 3 days; 50% of ETo with II of 2 days; 100% of the ETo irrigated daily, and 5 liters of water per linear meter every 15 days. Seven sampling distances: zero (in the center of the row); 0.15 m (lateral line position); 0.30; 0.50; 0.70; 0.85 and 1.00 m (central position of the row). Four sampling depths: 0 to 0.10; 0.10 to 0.20; 0.20 to 0.30 and 0.30 to 0.40 m. There were double interactions between water application and distance; Condition of water application and depths, and independent significance for each factor. The highest root concentration is found at a depth of 0.10 to 0.20 m and at distance of 0.15 m from the center of the row. The condition of 50% of the ETo with II of 2 days allows a greater development of roots. The conditions of 15% of ETo with II of 7 days and 33% of ETo with II of 3 days provide better water content conditions in regions with greater root distribution.

KEYWORDS: *Opuntia fícus*, irrigation management, roots

DISTRIBUIÇÃO RADICULAR E ÁGUA EM SOLO CULTIVADO COM PALMA FORRAGEIRA SOB DIFERENTES CONFIGURAÇÕES DE IRRIGAÇÃO

RESUMO: O conhecimento da distribuição de raízes das culturas no solo é de fundamental importância no manejo da irrigação e na aplicação de fertilizantes. Objetivou-se com este trabalho determinar os perfis de distribuição de raízes e de água no solo cultivado com palma

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forrageira Gigante sob diferentes combinações de lâminas de irrigação e turno de rega com água salina. O delineamento experimental foi em blocos casualizados com três repetições, seguindo um fatorial 7 x 7 x 4; sete condição de aplicação de água: sem irrigação; 7% da evapotranspiração de referência (ETo) com turno de rega (TR) de 15 dias; 15% da ETo com TR de 7 dias; 33% da ETo com TR de 3 dias; 50% da ETo com TR de 2 dias; 100% da ETo irrigado diariamente e, 5 litros de água por metro linear a cada 15 dias. Sete distâncias de amostragem: zero (no centro da fileira); 0,15 m (posição da linha lateral); 0,30; 0,50; 0,70; 0,85 e 1,00 m (posição central da fileira). E quatro profundidades: 0 a 0,10; 0,10 a 0,20; 0,20 a 0,30 e 0,30 a 0,40 m. Houve interações duplas entre condição de aplicação de água e distância; condição de aplicação de água e profundidades e significância independente para cada fator. A maior concentração de raízes fica compreendida na profundidade de 0,10 a 0,20 m e na distância de 0,15 m do centro da fileira. A condição de 50% da ETo com TR de 2 dias possibilita maior desenvolvimento de raízes. As condições de 15% da ETo com TR de 7 dias e 33% da ETo com TR de 3 dias proporciona melhores condições de umidade nas regiões de maior distribuição de raízes.

PALAVRAS-CHAVE: *Opuntia fícus,* manejo de irrigação, raízes

INTRODUCTION

Bahia state has two thirds of its territory in the semiarid region (Brasil, 2005). This region is characterized by low and irregular rainfall throughout the year, which according to Almeida (2011), it limits the production of natural pasture with high nutritional content to meet the ruminant livestock demand for food at certain period.

Forage cactus (*Opuntia ficus-indica*) is considered a xerophytic plant, and for this reason, it adapts to adverse semiarid conditions; though, its productivity has been low, especially because of improper management (DONATO, et al., 2014). The crop presents itself as food resource of extreme importance and stands out as a highly important succulent fodder for cattle, especially in periods of forage unavailability (Morais & Vasconcelos, 2007).

Despite there being studies regarding the crop production of forage cactus, information about the water demand of these crops is scarce, mainly for semiarid conditions. Therefore, it is necessary to determine the water need in order to better understand the yield response of this species under local soil and climate (Silva et al., 2014b). The irrigation water in arid and semiarid regions, especially the one that comes from tube wells, usually contains a high concentration of salts, which might be a problem for agricultural production of most crops (Silva et al., 2013); however, the use of sources of saline water is an alternative to mitigate the water supply crisis, chiefly in arid and semiarid zones of the planet (Embrapa Semiárido, 2012). Thus, the inclusion of low-quality water in the crop production system turned out to be a necessary alternative to meet the demand of irrigated crops (Silva et al., 2014a).

It is necessary to know the behavior of each component involved in the crop production so as to properly manage the irrigation. Among these components, the root distribution stands out, as it is responsible for the absorption of water and nutrients in the soil, and its knowledge allows determining the depth within the soil that should be watered, where to install sensors, and where to apply fertilizers, among others. Nevertheless, this profile can be changed by the chosen management. Therefore, this paper aimed at determining how roots and water are distributed in the soil cultivated by ‘Giant’ forage cactus under different combinations of scheduling and irrigation depths with saline water.

MATERIAL AND METHODS

The experiment was carried out at the agricultural sector of the Instituto Federal de Educação, Ciências e Tecnologia Baiano, *campus* Guanambi, Southern Bahia state, 14°17’27’’S and 42º46’53’’W, altitude of 537 m, average rainfall of 680 mm and average temperature of 26ºC.

The planting of cactus cv ‘Giant’ (*Opuntia ficus-indica* Mill) took place on October 23 and 24, 2014, with spacing at 0.14 m between plants and 1 m between rows, arranged in triple rows, spaced out 3.0 m apart, in a RED-YELLOW OXISOL. The trial was conducted over the period of two production cycles, up to October, 2016. The main weather variables recorded in this period were obtained by a weather station close to the experimental area (Figure 1).

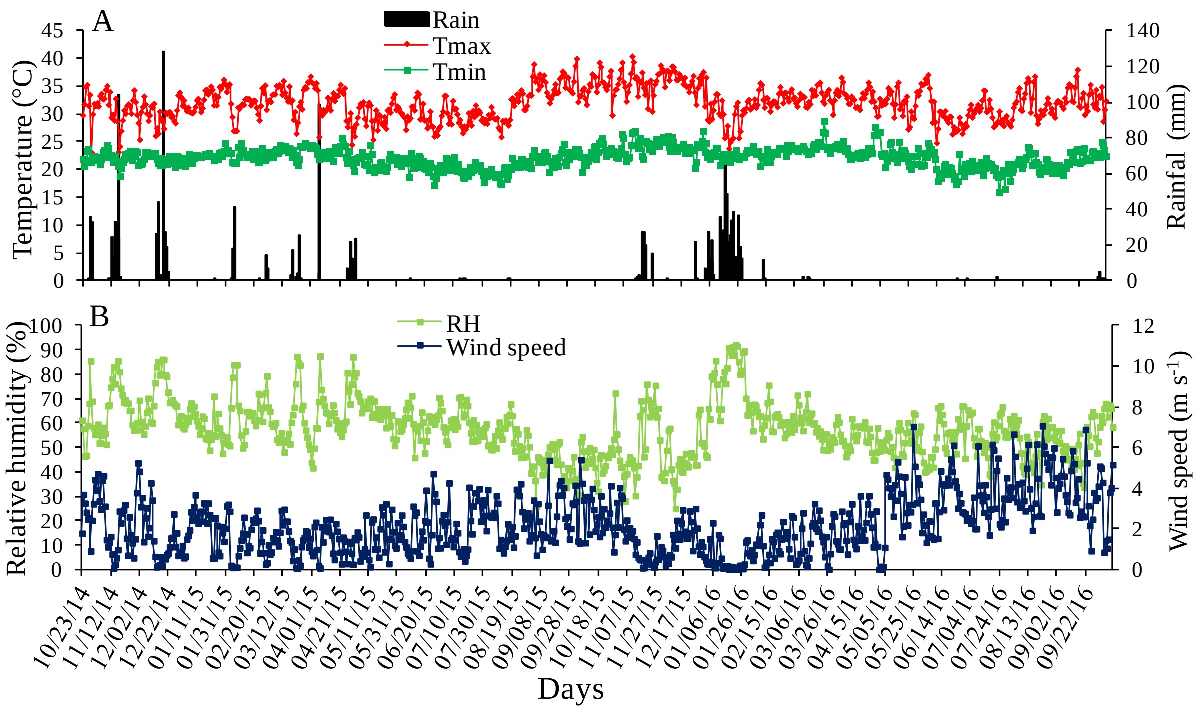

Figure 1. Maximum and minimum temperature, relative humidity and wind speed throughout the whole experiment. Automatic weather station. IF Baiano – *Campus* Guanambi, 2014-2016.

The study evaluated the root and water distribution under seven conditions of water application: rainfed; five litters of water per linear meter every 15 days; 7% of reference evapotranspiration (ETo) with a irrigation interval of 15 days (II); 15% of ETo with II of seven days; 33% of ETo with II of three days; 50% of ETo with II of two days and 100% of ETo, irrigated on a daily basis. These treatments were set in a randomized block design, with four replicates, which totaled 28 experimental units. Each experimental unit consisted of three 8-meter-long rows of plants, in which the 4 central meters of these three rows are where the useful plants were located, totaling 20 m^2 in area.

The ETo records were daily obtained from a weather station at 200 m from the experimental area. The irrigation time was calculated for each treatment, using the equation 1, for wet continuous strip (Santos & Brito, 2016).

$$IT = \frac{ETo\ x Sr\ x\ Se\ x\ Kl}{q\ x\ Ae} \quad (01)$$

which means,

IT - irrigation time (hours);

ETo – reference evapotranspiration (mm);

Sr – spacing between rows (m);

Se – spacing between emitters (m);

Kl – coefficient for localized irrigation;

q – emitter flow rate (L h^{-1}) and

Ae – application efficiency (%).

We used a drip irrigation system with preinstalled tortuous-path emitters, with a flow rate of 4 L h^{-1}, spaced out 0.5 m. The water used at the treatment with application of 5 liters of water per linear meter every 15 days has an electrical conductivity (CEw) of 0.75 dS m^{-1}, which as classified as C2S1. As for the remaining treatments, the water was classified as C4S1, according to Ayers & Westcot, 1985, both from tube wells. The accumulation of water in different conditions of water application in the two production cycles was monitored (Table 1).

Table 1. The accumulation of water (mm) in the first (A) and second (B) production cycles of 'Giant' forage cactus. IF Baiano – *Campus* Guanambi, 2017.

Treatment	AWC	1st Cycle		2nd Cycle	
		G	GW+R	GW	GW+R
T01	Rainfed	0	817,00	0,00	650,83
T02	5L/m IT15d	3	856,77	100,00	750,83
T03	7%ETo IT15d	6	878,84	125,61	776,44
T04	15%ETo IT7d	1	948,39	259,97	910,80
T05	33%ETo IT3d	2	1101,37	570,31	1221,14
T06	50%ETo IT2d	4	1258,72	860,11	1510,94
T07	100%ETo IT1d	8	1700,44	1717,90	2368,73

In each of the two production cycles, 30 t ha^{-1} of organic fertilizer was applied at planting time. Topdressing was performed after planting, with 60 t ha^{-1} of bovine manure; mineral fertilization, applied at planting, consisted of applying 300 Kg ha^{-1} of K_2O and 150 Kg ha^{-1} of P_2O_5, from which the fertilizer source were potassium chloride and simple superphosphate, respectively.

The soil moisture content was measured using TDR sensors (time-domain reflectometry), installed at 20 cm from the plant, at 10 and 30 cm deep, in each condition of water application. The readings were performed over the period of 82 days, an hour before irrigating. The TDR sensors were calibrated according to Santos et al., (2010) for estimating the water contents (θ) through the dielectric constant (Ka) (Equation 2).

$$\theta = 0.017\ Ka - 0.0839;\ r^2 = 0.99 \qquad (02)$$

After the harvest in the second cycle, for each condition of water application, roots from three plants located perpendicularly to the rows of plants were collected. The sampling started from the middle of the row, on the same side on which the lateral line was, towards to the other row on the side on which the lateral line was not. It formed a sampling grid within the soil profile. The roots were sampled at seven distances from the plant: 0.00, 0.15, 0.30, 0.50, 0.70, 0.85 and 1.00 m; and at four depths: 0.00 to 0.10; 0.10 to 0.20; 0.20 to 0.30, and 0.30 to 0.40 m. Each sample was collected with a cylindrical soil sampler, 10 cm high, and volume of 311.725 cm^3 (Vr).

The roots of each sample were separated from the soil by washing it off with water. Afterwards, the roots were scanned and turned into Tagged Image File Format – TIFF. These images were analyzed so as to remove dark borders caused by the process of digitalization; then, they were processed by the application Rootedge (Kaspar & Ewing, 1997) to determine the root length, Rl (cm), and root length density, RLD (cm cm^{-3}), in a given sample volume Sv (cm^3), in which RLD = Rl Sv^{-1}.

As for the analysis of root distribution, a 7x7x4 factorial was used, which consisted of seven conditions of water application, seven sampling distances and four depths, arranged in a randomized block design. The data of RLD were submitted to analysis of variance and classified according to their significance; the means of these variables were compared to each other by using the Scott-Knott test ($P<0.05$) for the factor 'condition of water application', and, for the factors 'distances' and 'depths', regression was used.

RESULTS AND DISCUSSION

The mean values of soil moisture content under the different conditions (Figure 1) exhibited coherent regarding the amount of water applied. It was observed that the water content at 10 cm has the highest variation throughout the days under the conditions of 15% of ETo with II of seven days, 33% of ETo with II of three days and 50% of ETo with II of two days, in comparison with the content at the depth of 30 cm. Under these conditions, this higher variation is probably related to the water evaporation in the upper layer of the soil due to the irrigation intervals.

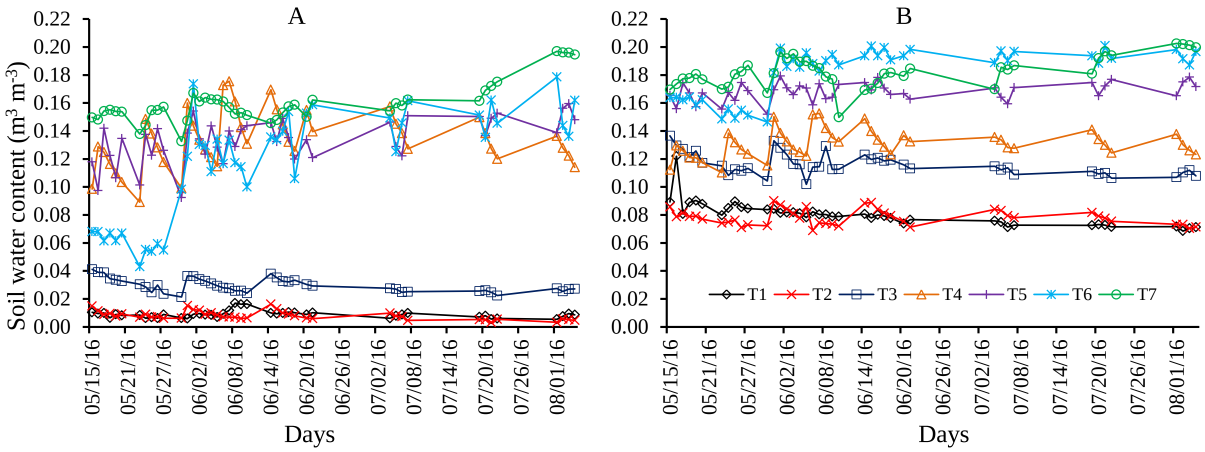

Figure 2. Water contents in the soil cultivated with 'Giant' forage cactus for different conditions of water application at the depths of 10 cm (A) and 30 cm (B). IF Baiano – *Campus* Guanambi, 2017.

The water contents under the condition of 100% of ETo, irrigated daily, at 10 m deep, and under the conditions of 50% of ETo with II of two days and 100% of ETo irrigated daily at 30 m deep (Figures 2 A and B), remained close to the field capacity (0.20 m^3 m^{-3}). The rainfed and 5 L m^{-1} every 15 days conditions exhibited similar water contents, as the amount of water applied was not enough to reach the depth of 10 cm. The water content in these conditions remained below the permanent wilting point (0.11 m^3 m^{-3}). The values below the wilting point are perhaps related to the permanence of empty spaces around the sensor, as it recorded low values of dielectric constants. These values were below those used during the calibration, in which it generated low values of water contents, not matching the actual values.

Through the analysis of variance, there was interaction between distance and condition of water application, as well as between depth and water application for root length density. The distribution profile for each condition of water application is shown in Figure 3 and the regression models for its estimates are in Table 2.

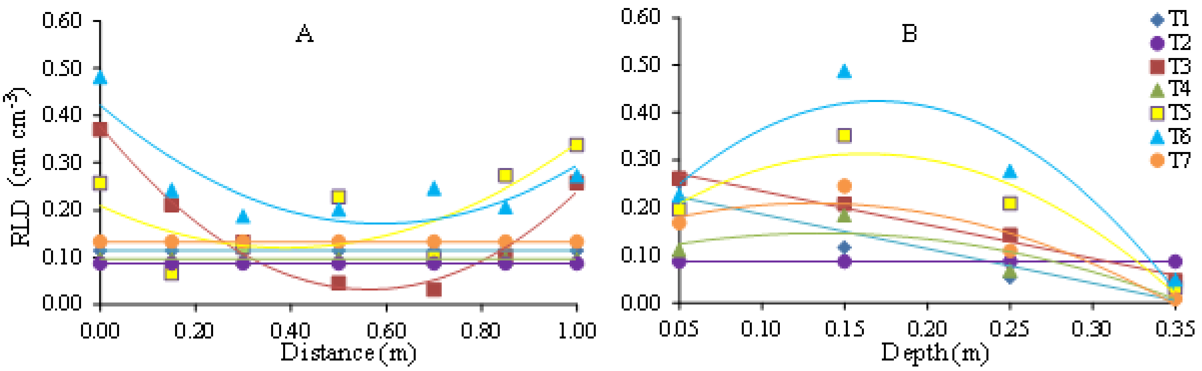

Figure 3. Root length density – RLD in function of the distance (A) and in function of the depth (B) for every condition of water application.

Table 2. Models for estimating the root length density (RLD) in function of sampling distance and depth for every condition of water application.

Distance	Depth
$RLD_{T1} = 0,1145$	$RLD_{T1} = -0,727x^{**} + 0,259$, $R^2 = 0,884$
$RLD_{T2} = 1,087x^{2**} - 1,225x^{**} + 0,377$, $R^2 = 0,979$	$RLD_{T2} = -0,709x^{**} + 0,306$, $R^2 = 0,980$
$RLD_{T3} = 0,0964$	$RLD_{T3} = -3,031x^2 + 0,825x + 0,090$, $R^2 = 0,765$
$RLD_{T4} = 0,590x^{2**} - 0,459x^{*} + 0,209$, $R^2 = 0,571$	$RLD_{T4} = -8,309x^{2**} + 2,688x^{**} + 0,095$, $R^2 = 0,932$
$RLD_{T5} = 0,723x^{2**} - 0,850x^{**} + 0,421$, $R^2 = 0,742$	$RLD_{T5} = -12,24x^{2**} + 4,153x^{**} + 0,072$, $R^2 = 0,893$
$RLD_{T6} = 0,1331$	$RLD_{T6} = -4,455x^{2*} + 1,164x + 0,134$, $R^2 = 0,898$
$RLD_{T7} = 0,0871$	$RLD_{T7} = 0,0871$

The highest root density was found at between 0.10 and 0.20 m deep and at 0.15 m from the center of the plant rows, mainly for the conditions with higher application of water and shorter irrigation interval. This can be explained by the higher availability of water in this region, which decreased the development of roots for the uptake of water in longer deeper regions within the soil. Santos et al. (2016) verified that the application of larger amounts of water in banana plants results in higher availability of water in the upper layer of the soil, thus favoring a higher development of roots in this layer; on the other hand, under lower availability of water, the roots tend to become deeper within the soil profile, which can be attributed to physiologic mechanisms to cope with abiotic stress by investing in root development.

Root distribution, represented by the RLD for different conditions of water application, is depicted in the Figure 3. By using the Scott-Knott test, the rainfed condition as well as the conditions of five liters of water per linear meter and 15% of ETo every 7 days exhibited lower development of roots; though, the condition of 50% of ETo applied every two days exhibited wider root distribution. Similar results were found by Santos et al. (2014). They worked with ‘Tommy Atkins’ mango trees under water deficit, and found lower root length density under rainfed condition than under irrigated condition.

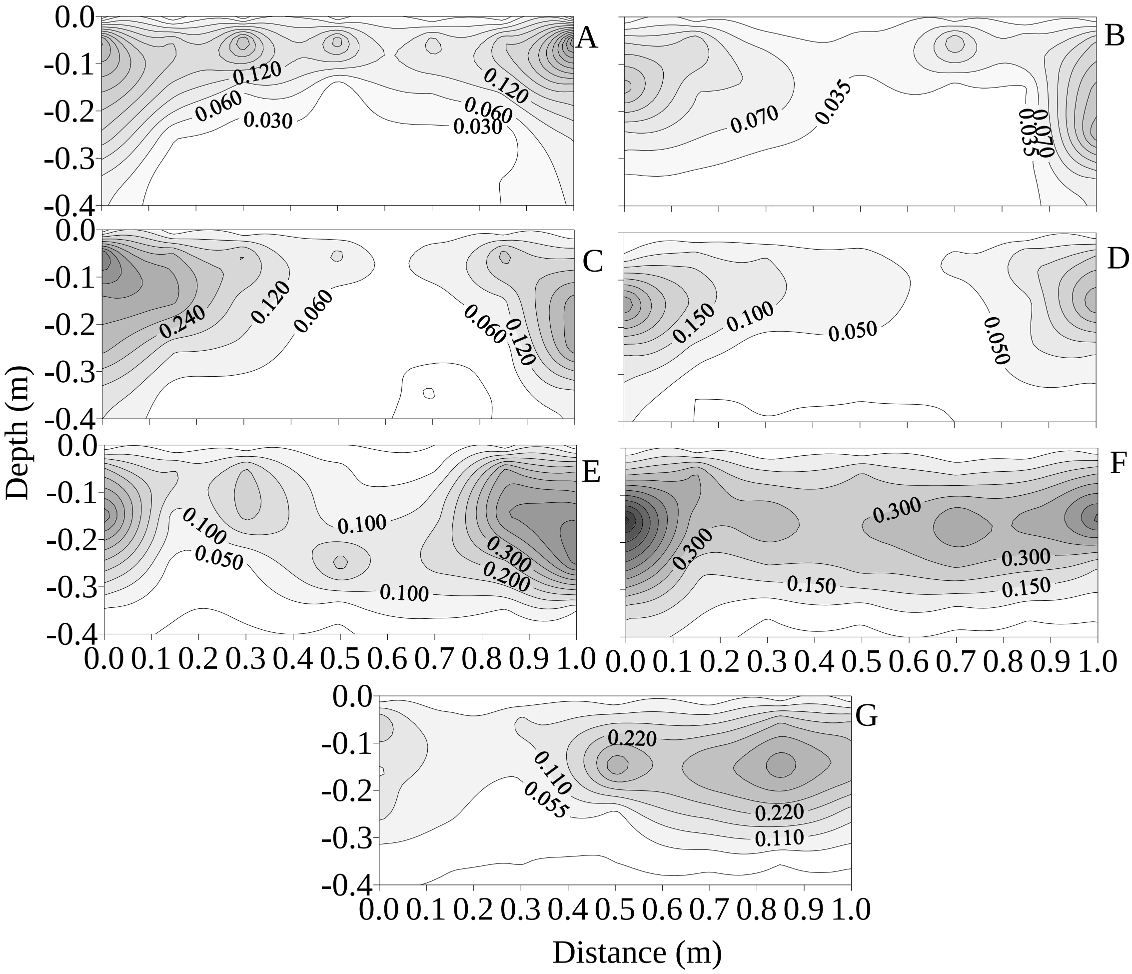

Figure 3. Root length density (RLD) for the rainfed condition (A); conditions of five liters of water per linear meter every 15 days (B); 7% of ETo with irrigation interval (II) of 15 days (C); 15% of ETo with II of seven days (D); 33% of ETo with II of three days (E); 50% of ETo with II of two days (F) and 100% of ETo irrigated on a daily basis (G).

CONCLUSIONS

The higher concentration of roots is within the depth of 0.10 to 0.20 m and at the distance of 0.15 m from the center of the row. The condition with 50% of ETo with II of two days allows a higher root development. The conditions of 15% of ETo with II of seven days, and 33% of ETo with II of three days improve the moisture condition in regions with higher root distribution.

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