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Sensor placement for irrigation scheduling in banana using micro-sprinkler system

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Abstract: Among the techniques that enable the correct scheduling of irrigation, the use of sensors that measure the water content of the soil may be mentioned. However, the location of the installations of the sensors in the field is not yet known. The aim of this work is to establish the location where the sensors may be installed for the management of the irrigation of banana crop by different systems of irrigation using microsprinkling. The study was conducted, considering the following systems: one microsprinkler of 32 L h^{-1} for four plants (T1); one microsprinkler of 60 L h^{-1} for four plants (T2); one microsprinkler of 60 L h^{-1} for two plants (T3). The soil moisture was monitored different horizontal distances and also depths, in a net of 0.20 x 0.20 m on a vertical plane using TDR. The zones for extraction of water were influenced by the distribution of water in the soil. The sensors can be located in the region which covers distances, measured from the pseudostem of 0.1 to 0.7 m, 0.1 to 0.8 m and 0.4 to 1 m, in the systems with a microsprinkler of 32 L h^{-1} for four plants, a microsprinkler of 60 L h^{-1} for four plants and a microsprinkler of 60 L h^{-1} for two plants, respectively. For all systems, the installation depth was limited to 0.25 m.

Key words: efficiency of irrigation, localized irrigation, *Musa* sp.

Posicionamento de sensores para o manejo da irrigação da bananeira por sistemas de microaspersão

Resumo: A ausência de manejo nos sistemas de irrigação é uma das principais causas da baixa eficiência no uso da água no setor agrícola. Dentre as técnicas que possibilitam o correto manejo da irrigação, destaca-se a utilização de sensores que medem o conteúdo de água no solo. Entretanto, não sabe-se ao certo o local de instalação dos sensores no campo. Diante disto, objetivou-se com este trabalho definir o local de instalação dos sensores para manejo da irrigação da bananeira por diferentes sistemas de irrigação por microaspersão. O trabalho foi realizado com os seguintes tratamentos: T1 - um microaspersor de 32 L h^{-1} para quatro plantas com uma lateral entre duas fileiras de plantas; T2 - um microaspersor de 60 L h^{-1} para quatro plantas com uma lateral entre duas fileiras de plantas; T3 - um microaspersor de 60 L h^{-1} para duas plantas com uma lateral entre duas fileiras de plantas. Os sensores podem ser localizados na região que compreende a distância do pseudocaule de 0,1 à 0,7 m, 0,1 à 0,8 m e 0,4 à 1 m, nos sistemas com um microaspersor de 32 L h^{-1} para quatro plantas, um microaspersor de 60L h^{-1} para quatro plantas e um microaspersor de 60 L h^{-1} para duas plantas, respectivamente. Para todos os sistemas, a profundidade de instalação teve seu limite em 0,25 m.

Palavras-chave: eficiência de irrigação, irrigação localizada, *Musa* sp.

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Introduction

The agricultural community sees the steady growth of irrigation as an imperative condition for achieving the goals set by the international community, in order to reduce hunger and poverty. In this regard, it is estimated that 29% more irrigated area shall be needed by the year 2025 (IWMI, 2000). The general perception is the need for increasing efficiency in agriculture as the solution to the water crisis.

To increase efficiency and the productivity of water and also to reach the required levels of food safety, an essential change in the current situation of waste of the irrigated agriculture production standards is indeed required (Toepfer, 1998). Nowadays, companies are more and more modern and better equipped and the success of the irrigation project could easily be achieved if this only depended on the quality of the project, the equipment and the implementation; however, the systems are managed by users who often do not know exactly when to apply irrigation water, nor how much to apply (Mantovani, 2006).

Among the techniques that enable the correct irrigation scheduling, one that stands out is the use of sensors that measure the soil water content. The most common sensors available are those based upon heat conductivity or capacitance, neutron scattering, gamma ray attenuation, time domain reflectometry (TDR) and tensiometers. The greatest difficulty observed by the farmers when using these techniques to establish when and how much to irrigate is to define how many sensors should be installed in an area, as also where to install. The establishment of sensor number to be installed in an area is strongly dependent on the spatial soil variability (Hendricks & Wierenga, 1990; Coelho Filho, 1998). With regard to the correct location, the recommendations are limited to a reduced number of crops and are based on knowledge of the root distribution (Salgado & Cautín 2008; Sokalska et al., 2009; Guohua et al., 2010; Ahmadi et al., 2011). However, studies have shown that the extraction of water by plant roots does not always occur in a direction proportional to the increase of root length density (Clothier et al., 1994). In this regard, Coelho et al. (2007) show that the correct location of the sensors should take into consideration the effective areas of water extraction by the roots, which vary according to the type of soil, irrigation system, crop variety and also the age of the plants (Zhang et al., 1996; Elmaloglou & Diamantopoulos, 2009; Hutton & Loveys, 2011). For Cruz et al. (2005) the scarcity of work along these lines is largely due to the difficulty of studying water flow in the root zone of the crop. In this regard, Heimovaara et al. (2004) report that the technique known as time domain reflectometry (TDR) has become a standard tool for the studies that involve time and spatial processes for the distribution of water in the soil, mainly due to their high precision and automation potential.

Information about the place where the water sensors are to be installed in the soil, based on the zones of water extraction by tropical fruit plants are still scarce, and in the specific case of the banana crop irrigated by microsprinkler system there is no record of such information in the literature. Thus, the purpose of this study is to characterize the effective zones of root length and also extraction of water by banana crop when irrigated using different irrigation systems using micro-sprinkling, as well to show the correct placing of water sensors on the ground, for the purposes of irrigation scheduling.

Material and Methods

The present study was carried out at the EMBRAPA Cassava and Fruits, at Cruz das Almas in the State of Bahia, Brazil (12°48'S; 39°06'W; 225 m), where the annual mean rainfall is of 1,143 mm. An area planted with the cv. BRS Tropical banana, in the production phase, during the first cycle, spaced at 3.0 x 2.5 m was used for the present study. The soil is a typical distrophic Yellow Latossol with the physical characteristics as shown in Table 1.

Three different trickle irrigation systems have been studied. The treatments T1, T2 and T3 were identified as follows: T1 – a microsprinkler of 32 L h^{-1} irrigating four plants with one lateral line between two plant rows; T2 – a microsprinkler of 60 L h^{-1} irrigating four plants with one lateral line between two plant rows; T3 – a microsprinkler of 60 L h^{-1} irrigating two plants with one lateral line close to a plant row. Each treatment consisted of a total of 10 plants, and the measurements of root distribution, matric potential and of the available water in the soil, as well as water extraction were carried out using a single plant. The volume of applied water was same for all treatments based on calculation of requiriment. The reference evapotranspiration (ETo) was obtained from meteorological data collected on the same experimental field where research was carried out and for the calculation of crop evapotranspiration (ETc) crop coefficients were used as suggested by Doorenbos & Kassam (1984) and a reduction

Table 1. Physical characteristics of the soil of experimental area

Depth (m)	Granulometric composition (%)			Textural classification	Porosity (%)		Soil density (kg dm³)	Soil water content (m³ m⁻³)		Hydraulic conductivity (m s⁻¹ x 10⁻⁷)
	Total sand	Silt	Clay		Macro	Micro		-10 kPa	- 1500 kPa	
0 – 0.2	57.7	9.9	32.4	Sandy clay loam	13.34	26.34	1.50	0.2106	0.1495	160.00
0.2 – 0.4	51.7	8.9	39.4	Sandy clay loam	11.91	28.44	1.48	0.2400	0.1709	45.28
0.4 – 0.6	49.3	37.4	37.4	Sandy clay loam	11.92	26.14	1.52	0.2195	0.1625	200.00

coefficient (Kr) based on the surface of the soil which was effectively covered by banana leaf area. The frequency of irrigation was daily. The soil moisture was monitored at several different horizontal distances (R) and also depths (Z), in a net of 0.20 x 0.20 m on a vertical plane, starting from the plant and following the direction of the plant row, with "R" limit set at 1.0 m and a "Z" limit also set at 1.0 m. TDR probes were installed horizontally at the different points of the mesh, so that one could obtain the soil water content in the whole the plane (Figure 1).

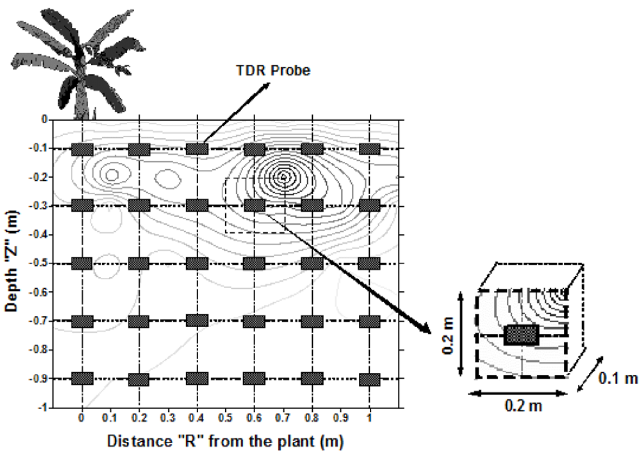

Figure 1. Monitoring of soil water content in the region around the root system of banana plants, using time domain reflectometry (TDR) probes

TDR probes were made with rods of 0.1 m spaced with distances of 0.017 m between them, as used by Silva et al. (2009), with the calibration equation given by Eq. (1):

$$\theta = 6.438\varepsilon^3 - 5.5246\varepsilon^2 + 2.0373\varepsilon - 0.0745 \quad (1)$$

where:

ε - bulk dielectric constant of the soil

As the TDR probes were installed, samples of 0.0005 m³ of soil and roots were removed from the profile in order to establish root distribution of the banana crop. Roots were separated from the soil using a washing process (Bohm, 1979), and then digitalized using a scanner (Coelho & Or, 1998). Root length "Lr" (cm) was obtained with the use of the Rootedge software (Kaspar & Ewing, 1997) and of root length density (RLD) was obtained using the following equation:

$$RLD = \frac{L_r}{V_r} \quad (2)$$

where:

RLD - density of root lengths, m m⁻³

L_r - length of roots, m

V_r - volume of samples, m³

Soil water content measurements were started thirty days after installation. Readings were made in each plane for a period of five days by using a TDR attached to a datalogger, programmed to store soil water content every 10 min. At each point of the grid (R, Z) the extracted water depth [LE(R, Z)] was calculated based on the differences of soil water content measured straight after irrigation (time corresponding to that when the infiltrated water would have reached the deepest probe in the plane (k + 1), and a time before the next irrigation (k + 2), as shown in Figure 2.

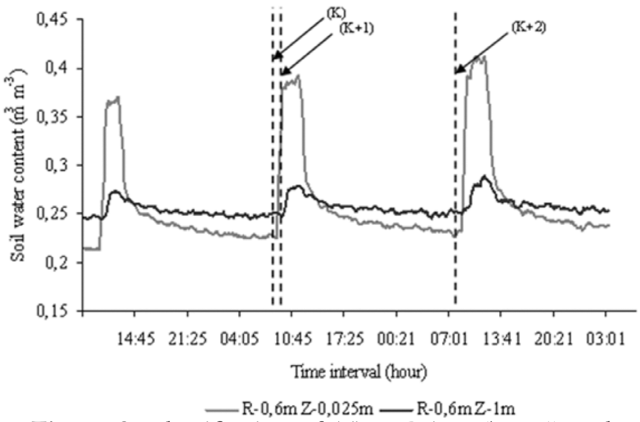

Figure 2. Identification of Time Points (k + 1) and (k + 2)

Extracted water by the plant was estimated at different locations on the grid [LE(Ri, Zi)] by using Eq. (3).

$$LE(R, Z) = \theta_{(k+1)} - \theta_{(k+2)} \quad (3)$$

where:

$\theta_{(k+1)}$ - soil water content immediately after irrigation, m³ m⁻³

$\theta_{(k+2)}$ - soil water content immediately before the following irrigation, $m^3 m^{-3}$

The concentration limits for the roots of banana plant have been established based on the knowledge of the effective root depth (ERD) and also the effective root distance (ERDi), with "EDR" being defined as the depth that contains 80% of total root length and "ERDi" as the distance that contains 80% of the total root length. A characterization of the effective extraction depth (EED) and the effective extraction distance (EEDi) was made based on the knowledge of the zone where most of root activity occurs. The effective extraction depth (EED) corresponded to the region of the soil profile, starting from the soil surface, where at least 80% of the total water is extracted by roots and EEDi corresponded to the region of the soil profile from the plant, where at least 80% of the water is also extracted by the roots. The percentages of soil available water were established at each location of the profile (R, Z), based on the soil water characteristic curve by Eq. (4):

$$AD(R,Z) = \left(\frac{\theta(R,Z) - \theta_{pmp}}{\theta_{cc} - \theta_{pmp}} \right) \times 100 \qquad (4)$$

where:

AD(R, Z) - percentage of available water at a point (R, Z) in the soil profile

θ(R, Z) - soil water content at a point (R, Z) of the soil profile, $m^3 m^{-3}$

θ_{pmp} - soil water content referring to permanent wilting point, $m^3 m^{-3}$

θ_{cc} - soil water content referring to field capacity, $m^3 m^{-3}$

Percolation loss, DP (R, Z_R) can be calculated by Eq. (5) for each distance R just below the effective depth of the roots, Z_R that was assumed as 0.9 m:

$$DP(R, Z_R) = \int_{k+1}^{k+2} q\,dt \qquad (5)$$

where:

k + 1 - time when soil water content reached its maximum value at shallow locations (R, Z) and the wetting front reached the depth of 0.9 m

k + 2 - time of the next irrigation

$$q = \frac{\theta_t - \theta_{t+1}}{\Delta t} \qquad (6)$$

where:

Δt - time interval, 1 h

q - flow of water, $cm^3 h^{-1}$, in 1 cm^3 of the soil

θ_t - soil water content at the time t

θ_{t+1} - soil water content at the time t + 1

The average percolation loss in the profile, i.e, from plant to a distance R can be calculated by the Eq. (7):

$$DP_m = \frac{\sum_R DP(R, Z_R)}{n} \qquad (7)$$

where:

n - number of distances (R) from the plant

The values of DPm calculated for different moments in time after the beginning of irrigation for treatments T1, T2 and T3 were compared by the least significant difference (LSD) test at a probability level of 0.05.

Results and Discussion

Water distribution and deep percolation

Results showed that the largest precipitation values were always registered on the collectors furthest away from the plants and close to the microsprinklers, and there were records of precipitations of 5.1, 10.2 and 5.0 mm at a distance of 1 m, while at a distance of 0.2 m the precipitations as observed were 1.05, 0.35 and 2.02 mm for the treatments T1, T2 and T3, respectively (Figure 3).

There was the loss of water by percolation in all studied treatments. Table 2 presents average values of percolated water depths at different moments after the beginning of irrigation for treatments T1, T2 and T3. By comparison of the means for treatments at specific times, the values of the percolated water depths varied significantly based on the configurations of the irrigation systems, tested up to 1 hour after the start of irrigation and, after 2 and 4 hours the means were different and only higher in the case of treatment T2. There were no significant differences in the mean percolated water depth values between 6 and 14 h after the start of irrigation.

Root distribution

The isolines of distribution of root length density in the soil profile and also the percentage of cumulative root length in the soil profile at horizontal distances towards the microsprinkler and depths are shown in Figures 4 and 5. The effective root depths in case of a microsprinkler of 32 L h^{-1} for four plants (T1), a microsprinkler of 60 L h^{-1} for four plants (T2) and a microsprinkler

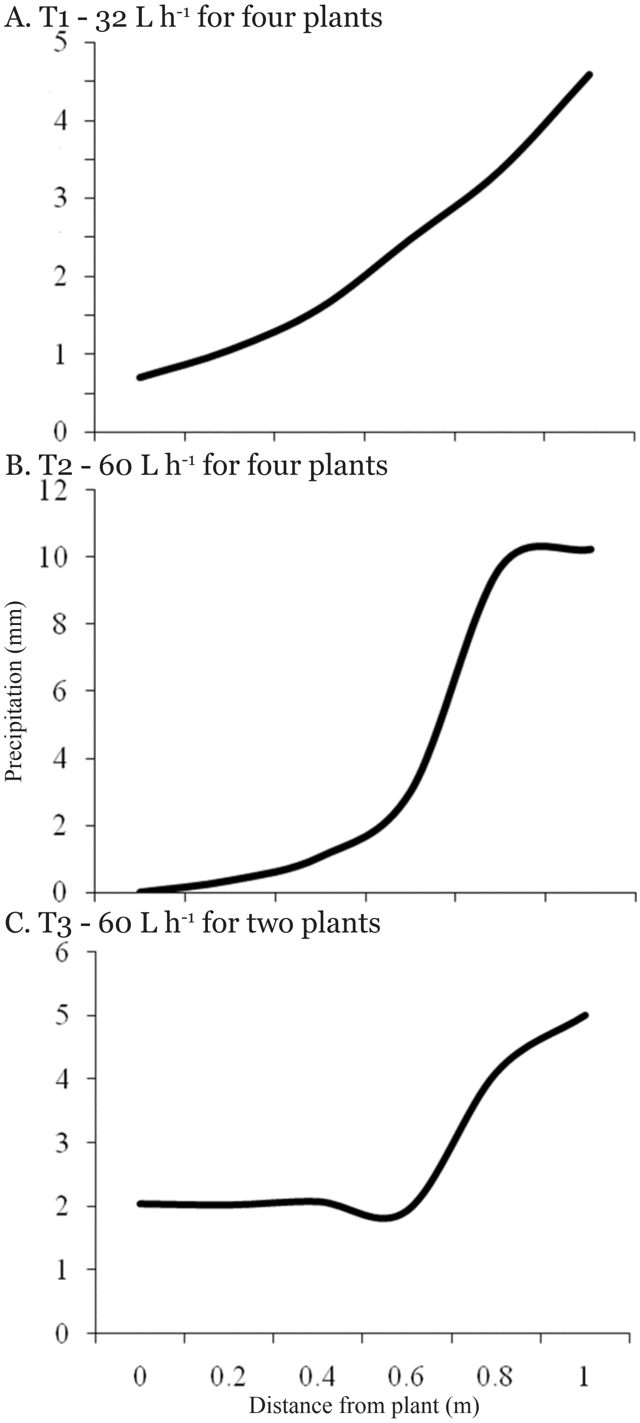

Figure 3. Precipitation in relation to the distance of the plant from the microsprinkler regarding treatments T1 (A), T2 (B), T3 (C)

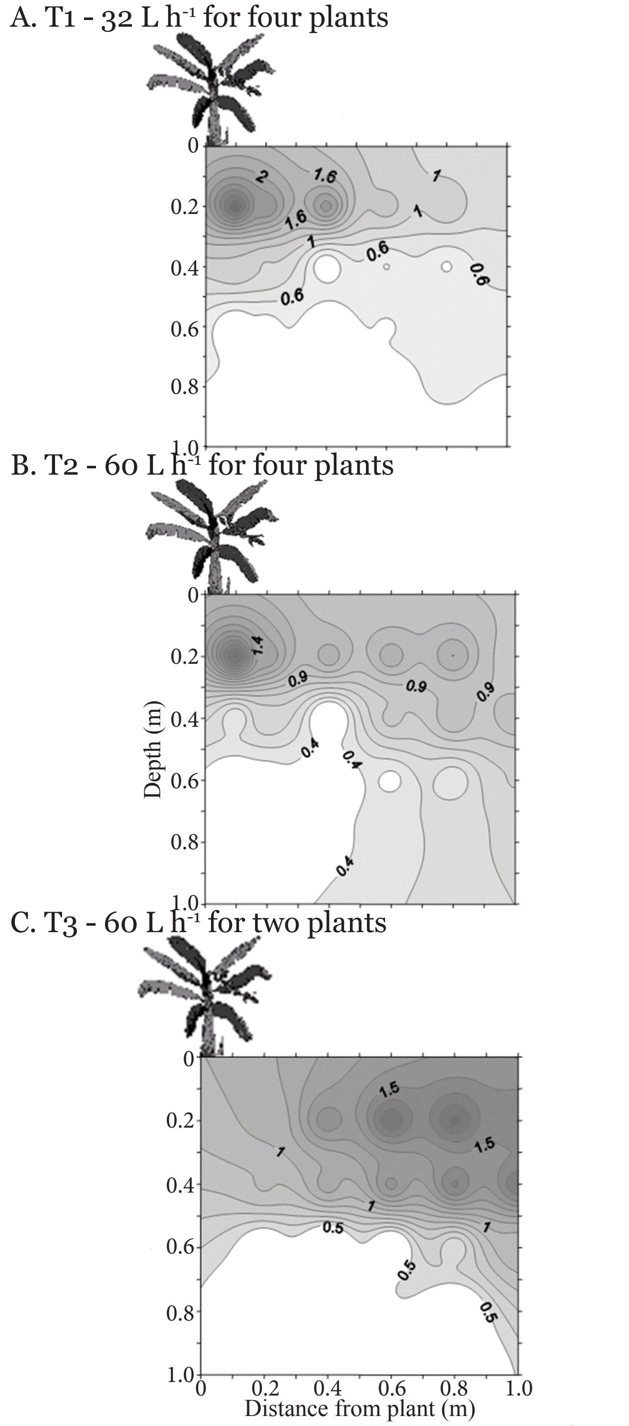

Figure 4. Isolines of root density length (in m^{-3}) of banana plants using the treatments T1 (A), T2 (B) and T3 (C)

of 60 L h^{-1} for two plants (T3) were 0.5, 0.5 and 0.6 m, respectively. Similar values were obtained by Ramos (2001) and Garcia (2000). The effective distances of the roots extended to 0.8, 0.85 and 0.7 m for treatments T1, T2 and T3, respectively.

Soil water extraction

Figure 6 shows the percentage distribution of the water availability in the soil immediately after the end of the irrigation. Superimposing the isolines of available water, the isolines for

Table 2. Mean percolation values at different times (hours - h) after irrigation

Treat.	Percolated water (mm)							
	1h	2h	4h	6h	8h	10h	12h	14h
T1	0.1878ab	0.1165a	0.1147a	0.1015a	0.0871a	0.0344a	0.0117a	0.0056a
T2	0.2531b	0.4960b	0.2416b	0.1024a	0.0752a	0.0970a	0.0136a	0.0009a
T3	0.1097a	0.1175a	0.0968a	0.1156a	0.0953a	0.0419a	0.0253a	0.0118a

* Means followed by the same letter do not show statistically significant differences according to the t-test (LSD) at a probability level of 0.05
\# T1, T2 and T3 correspond respectively to a microsprinkler of 32 L h^{-1} for four plants, 60 L h^{-1} for four plants and 60 L h^{-1} for two plants

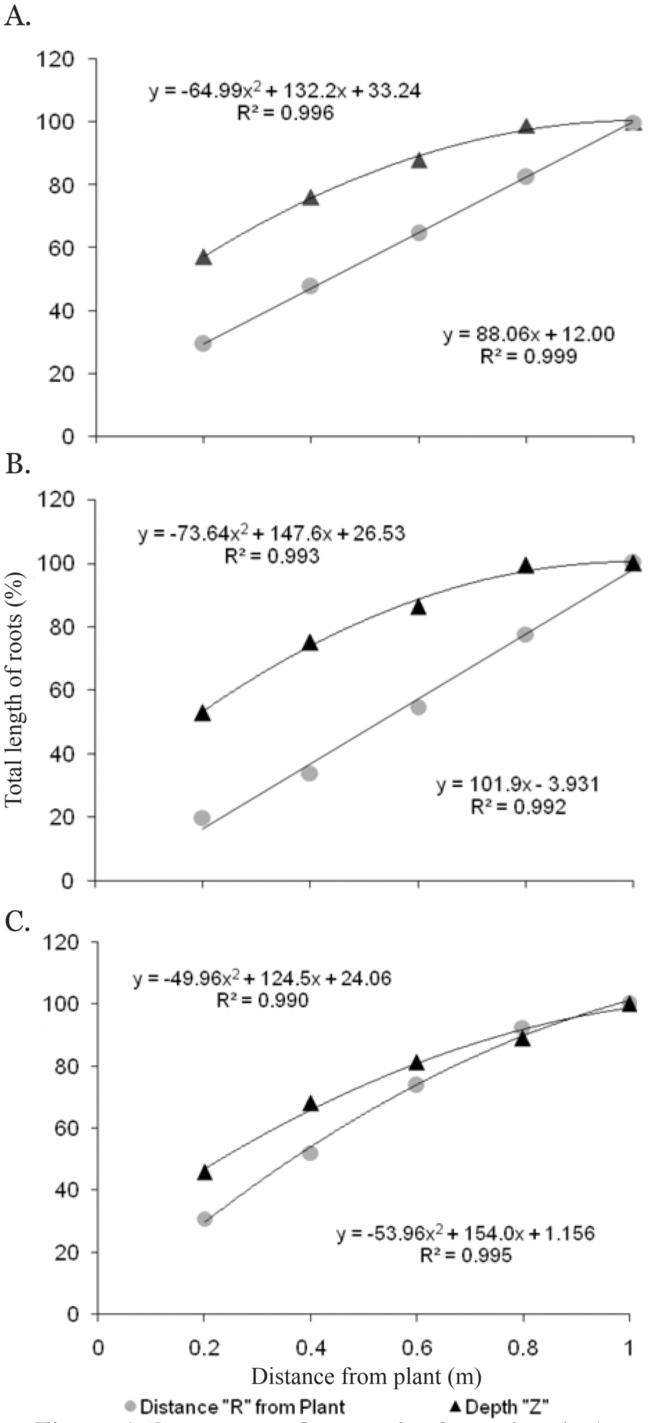

Figure 5. Percentages of accumulated root lengths in the soil profile at horizontal distances towards the micro-sprinkler (R) and depths (Z)

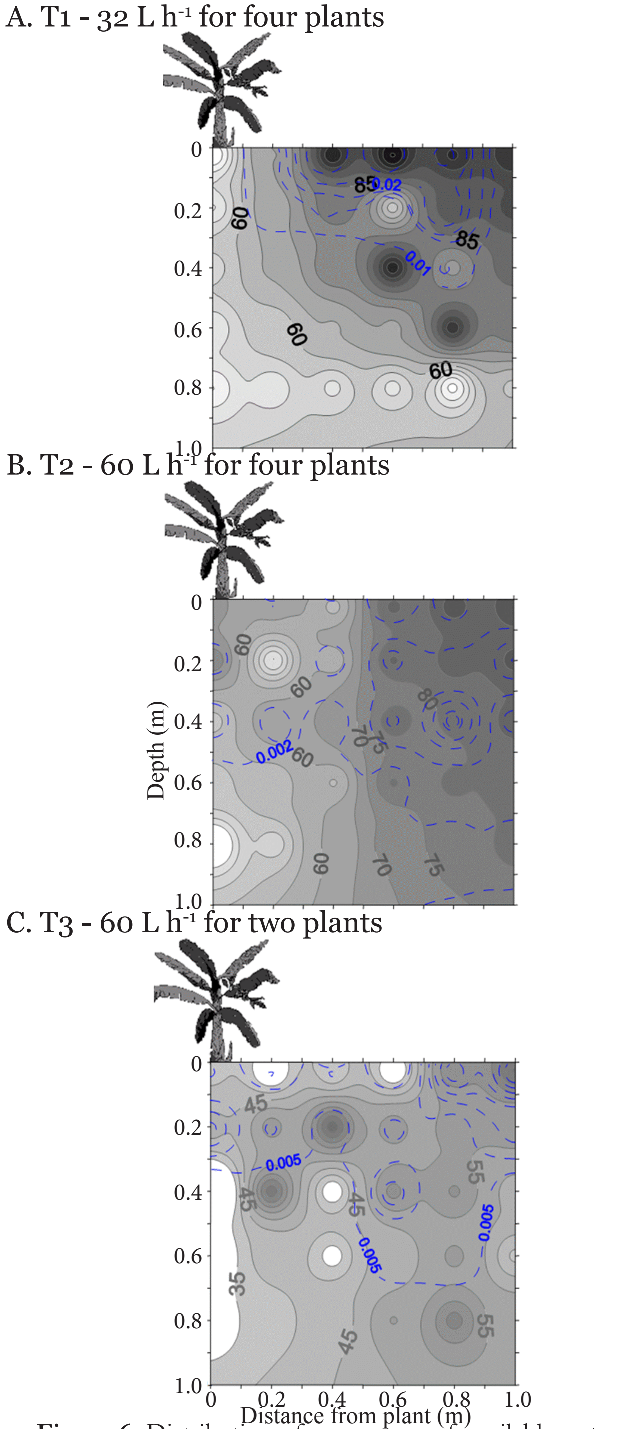

Figure 6. Distribution of percentage of available water on the ground and also in the water extraction zones in the soil, for T1 (A), T2 (B), T3 (C)

the water extraction from the soil between times k+1 and k+2 was observed (blue dashed lines). The distribution of available water takes place in a nonuniform way, i.e., the soil water contents get higher from the plant towards to the microsprinkler, coinciding to the regions where the largest volumes of water were collected on the soil surface, as applied by the microsprinklers.

It is also observed thet the zones for extraction of water were influenced by the distribution of water in the soil. The mean percentage of available water of 64.44% for treatment T1 was obtained at a distance of 0.2 m and the percentage of water extracted was 11.38% of the total extracted from the effective root distribution zone. The available water was 94.09% at the distance of 0.8 m where the extraction was 30.95% of the total. The percentage of water available in treatment T2 was 49.3% soon after the end of irrigation at a distance of 0.2 m, with a total occurrence of 10.83% of the total water extracted by the plant. The mean soil water available was 84.26%, for this same treatment but at a distance of 0.8 m with the occurrence of 31.76% of the total water extraction.

In treatment T3, the mean soil water available at 0.2 m was 57%, where there was also 8.17% of the total water extraction. The water content was 60.67%, with 24.42% of the total extraction of water at the distance of 0.8 m. These results emphasize the ones found by other authors (Zhang et al., 1996; Elmaloglou & Diamantopoulos, 2009; Hutton & Loveys, 2011) in which, the irrigation system affected the zones of water extraction by the plant. Staring from the pseudostem of the plants, effective water extraction distance of up to 0.7, 0.8 and 0.9 m was obtained for a microsprinkler of 32 L h^{-1} for four plants, a microsprinkler of 60 L h^{-1} for four plants and also a microsprinkler of 60 L h^{-1} for two plants, respectively. Effective water extraction depth observed was 0.25 m for all systems (Figure 7).

Sensor placement

Water sensors can be installed in the soil region which covers distances between 0.1 and 0.7 m, and can be installed to a depth of 0.25 m in system T1 (Figure 8A). In case of system T2, sensors can be installed up to a distance of 0.8 m from the pseudostem of the plant, with the maximum depth being 0.25 m (Figure 8B). In the case of system T3, sensors may be located at a distance of 0.4 m up to a distance of 0.9 m, with the maximum depth being 0.25 m (Figure 8C).

With the use of tensiometers, due to the fact that this technique is limited to a tension of 80 kPa, the installation region was reduced to the locations, where potentials observed were above -80 kPa before the start of irrigation. The suitable location for installation of tensiometers for treatment T1

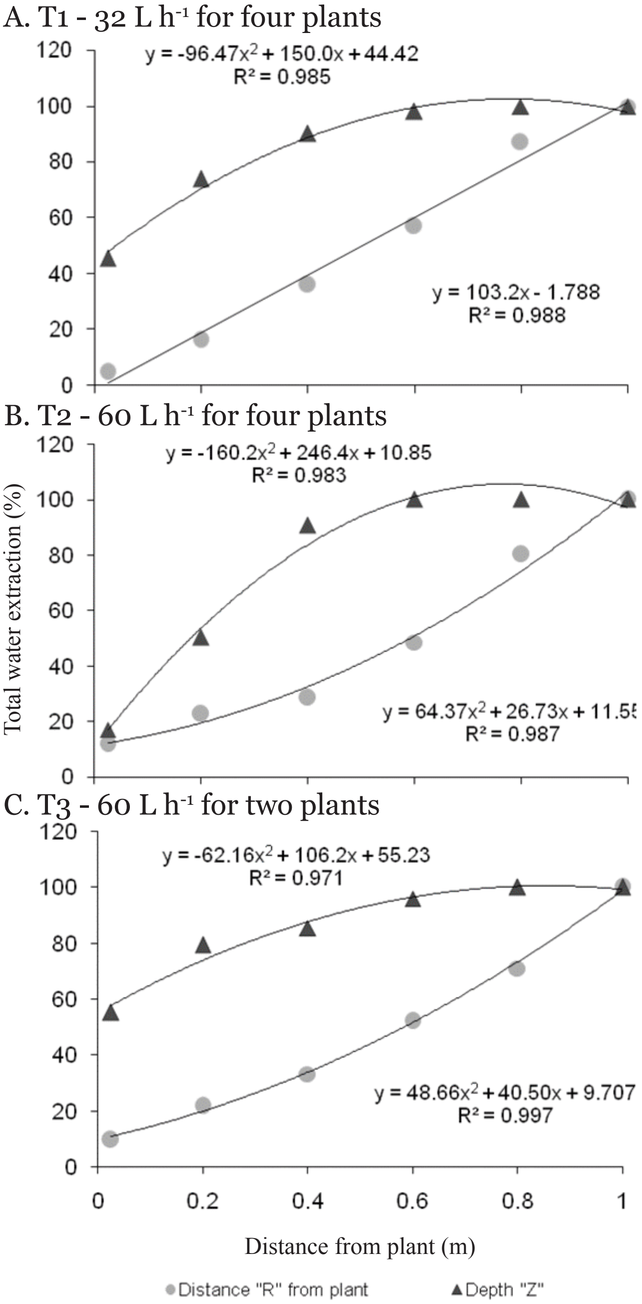

Figure 7. Percentages of accumulated water extraction, by distance and depth, for T1 (A), T2 (B), T3 (C)

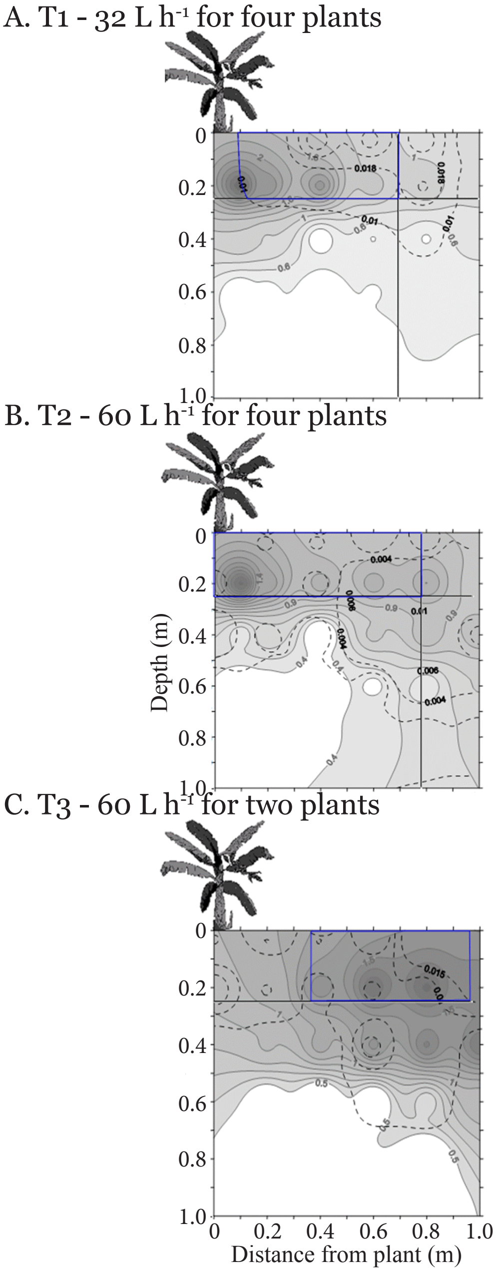

Figure 8. Suitable region for the location of water sensors in the soil (limited in blue) for the treatments: T1 (A), T2 (B) and T3 (C)

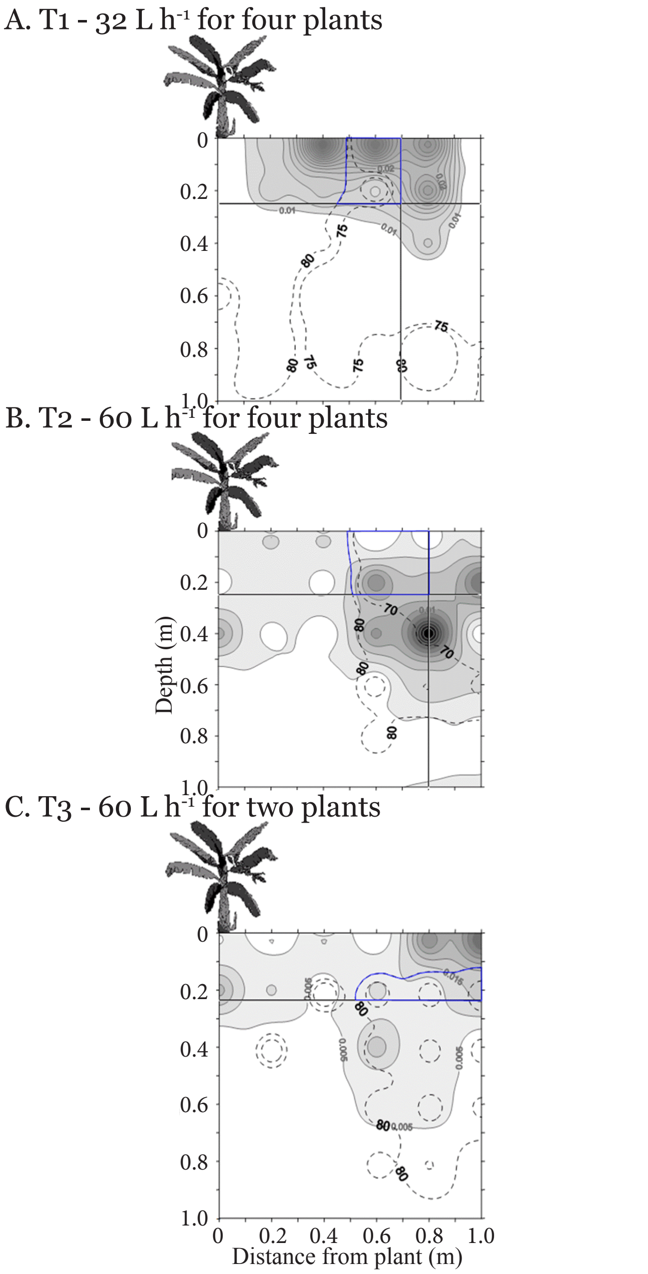

Figure 9. Suitable region for the tensiometers placement in the soil (delimited by the blue line) for treatments T1 (A), T2 (B) and T3 (C)

is the region between 0.5 and 0.7 m from the plant, limited to a depth of 0.25 m (Figure 9A). In treatment T2, the region for the installation of tensiometers is that comprising between 0.5 and 0.8 m, with a maximum depth of 0.25 m (Figure 9B). In treatment T3, it is recommended that the tensiometers be installed at a distance between 0.5 m and 1 m, at a depth of 0.2 m (Figure 9C).

Conclusions

1. The sensors to monitor water content for irrigation scheduling can be located in the region which covers distances, measured from the pseudostem, of 0.1 to 0.7 m, 0.1 to 0.8 m and 0.4 to 0.9 m, in the systems with a microsprinkler of 32 L h^{-1} for four plants, a microsprinkler of 60 L h^{-1} for four plants and a microsprinkler of 60 L h^{-1} for two plants, respectively.

2. For all systems, the installation depth should be limited to 0.25 m.

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