

Soil water distribution and extraction by ‘Tommy Atkins’ mango (*Mangifera indica* L.) trees under different irrigation regimes

Distribución y extracción de agua del suelo por la planta de mango ‘Tommy Atkins’ (Mangifera indica L.) bajo diferentes regímenes de riego

Marcelo Rocha dos Santos^{1*}, Mauro Aparecido Martinez²

ABSTRACT

The objective of this study was to determine the water distribution and extraction by mango variety ‘Tommy Atkins’ under different irrigation regimes. The treatments were: 1-Irrigation supplying 100% of ETc from flowering to fruit harvest; 2-50% of ETc from beginning of flowering to the beginning of the expansion of fruit and 100% of ETc to physiological maturity; 3-100% ETc from the onset of flowering to the beginning of fruit growth, 50% from the beginning of expansion to the start of physiological maturation and 100% during physiological maturation of the fruit; 4-100% ETc from the onset of flowering to the expansion of the fruit and 50% during physiological maturation; 5-Without irrigation. The soil water content was monitored using TDR between the end of phase I and the beginning of Phase III. The irrigation regimes caused different profiles of distribution and extraction of water through the mango tree. The extraction of water regardless of the treatment is primarily a within a distance less than 1.50 m from the plant and the first 0.50 m depth.

Key words: RDI, micro-sprinklers, root system, TDR.

RESUMEN

El objetivo de este trabajo es determinar la distribución y extracción de agua por la planta de mango ‘Tommy Atkins’ bajo diferentes regímenes de riego. Los perfiles de distribución de extracción de agua fueron determinados para los siguientes tratamientos: 1-Riego suministrado al 100% de la ETc en las fases: I (inicio de la floración al inicio de la expansión de los frutos), II (inicio de la expansión hasta el inicio de la maduración fisiológica) y en la fase III (maduración fisiológica de los frutos); 2-RDI con el 50% de la ETc en la fase I; 3-RDI con el 50% de la ETc en la fase II; 4-RDI con el 50% de la ETc en la fase III; 5-Sin riego. El monitoreo del contenido de agua en el perfil del suelo fue realizado entre el final de la fase I e inicio de la fase III con el uso de TDR. El régimen de riego ocasiona diferentes perfiles de distribución y extracción de agua por la planta de mango, en la cual, la extracción de agua independiente del tratamiento ocurre principalmente a la distancia inferior a 1,50 m de la planta y en los primeros 0,50 m de profundidad.

Palabras clave: RDI, microaspersión, sistema radicular, TDR.

Introduction

In recent years, considerable increases both in agricultural production as well as in cultivated area have been noticed in the scenario of irrigated agriculture. Fruit trees play a very important role in this context, and Brazil is one of the leading countries today in the area of fruit growth and yield. Mango (*Mangifera indica* L.) is by far the most important fruit crop grown in Brazil, and the most important plantations are found in the northeastern region of the country.

In Brazil, the most important States in terms of mango production are Bahia (45.1%), Pernambuco (16.44%), São Paulo (15.59%), Minas Gerais (8.26%), and Ceará (3.65%) (IBGE, 2011). The northeastern region is responsible for 73.41% of the mango produced in Brazil, with very prominent areas in Juazeiro, Livramento de Nossa Senhora, Rio Corrente, Itaberaba, and Ceraíma/Estreito, all located in the semiarid region of the State of Bahia, where fruit crops are grown under irrigation.

The most important irrigated areas are located in regions where water is scarce or unevenly

¹ Instituto Federal de Educação, Ciência e Tecnologia Baiano-Campus Guanambi, PO Box 009, District of Ceraíma, Zip Code 46430-000, Guanambi, Bahia, Brazil. Email:

² Universidade Federal de Viçosa, Agricultural Engineering Department, Viçosa, Minas Gerais, Brazil.

* Corresponding author: marcelo.rocha@guanambi.ifbaiano.edu.br

distributed, and the increase in cultivation demands more intensive use of water resources. Therefore, from an integrated viewpoint of conservation of water resources associated with yield increases, it is mandatory that strategies that maximize the efficiency of irrigation management be adopted.

Some regions have been adopting strategies of irrigation management that favor the rational utilization of water resources. In this context, techniques denominated irrigation with controlled deficit, such as Regulated Deficit Irrigation (RDI) and Partial Rootzone Drying (PRD) are worth mentioning.

The RDI technique was originally employed in peach (*Prunus persica* L.) and pear (*Pyrus* spp. L.) orchards, in order to control vegetative and reproductive growth, by means of imposing water stresses during important phases of fruit development (McCarthy, 2000). The RDI technique consists of delivering irrigation water with deficits at developmental stages when plant growth and fruit quality present low sensitivity to water stress; in other words, when it is possible to reduce water and energy consumption without compromising fruit quality and orchard yield. On the other hand, irrigation management based on PRD consists of alternating the side of the plant which receives irrigation during 10 to 14 days, from fruit set to fruit harvest. PRD is based on plant biochemical responses to achieve balance between vegetative and reproductive development by means of water stress and, in consequence, a significant increase in yield per unit of irrigation water applied is obtained (McCarthy, 2000).

Several investigators (e.g. Coelho Filho *et al.*, 2005; Spreer *et al.*, 2007, 2009; Silva *et al.*, 2009; Cotrim, 2011) have studied the utilization of RDI for growing mango trees and have obtained interesting results, from water and energy economy to increases in fruit quality and productivity maintenance.

The utilization of such strategies contributes to water extraction by the crop from different zones of the soil, and knowing the regions of water absorption by plant roots in the soil is thus necessary for moisture monitoring studies in order to manage irrigation, as well as to perform fertilization via soil or water.

Very few studies regarding water absorption by plants can be found in the literature, and for fruit trees, there are studies about water absorption by the roots of papaya (*Carica papaya* L.) trees (Silva *et al.*, 2001; Coelho *et al.*, 2002), banana (*Musa* spp.

L.) trees (Coelho *et al.*, 2010; Silva *et al.*, 2009), mango trees (Santos, 1997), and citrus (Simões, 2007; Santos *et al.*, 2005; Cruz *et al.*, 2005). However, studies of water extraction by plants grown under RDI and PRD irrigation strategies are very scarce.

Understanding the zones of water absorption by the root system, at different intensities, may help to adequately install and position soil water sensors (Machado & Coelho, 2000; Coelho *et al.*, 2007; Coelho *et al.*, 2010), besides helping to define the soil surface area where fertilizers should be applied so as to be more efficiently utilized by the crops (Silva *et al.*, 2005).

Therefore, the objective of this study was to determine the distribution and extraction of water from the soil by 'Tommy Atkins' mango trees under different irrigation regimes.

Material and Methods

This study was carried out in the experimental field of Companhia de Desenvolvimento dos Vales do São Francisco e Parnaíba (Company for the Development of Sao Francisco and Parnaiba River Basins-CODEVASF), located in the Perímetro Irrigado de Ceraíma (Ceraíma Irrigation Perimeter), in the town of Guanambi, Southwestern Bahia, Brazil. The region is geographically located at 14°17'27" S, and 42°46'53" W, with an altitude of 537m, average annual rainfall of 680 mm, and average annual temperature 25.6 °C. The soil at the experimental site is described as Eutrophic Fluvisol of medium texture, with high activity clays (Table 1).

Three irrigation regimes were employed, regulated deficit irrigation (RDI), full irrigation, and no irrigation whatsoever, and their influences on water distribution and extraction by Tommy Atkins mango trees were studied from blooming to fruit maturation. The orchard was 11-12 years old; trees were spaced at 8 m by 8 m. Plants were irrigated with micro sprinklers, one per plant, and received 50 Lh⁻¹ of water at 200 kPa.

Orchard maintenance and field practices adopted during the study period followed those common for the mango crop in the region. Two growth cycles were evaluated, and, after harvest, each plant was trimmed and fertilized with 500 g monoammonium phosphate (MAP), 200 g ammonium sulphate, 150 g potassium chloride, and 20 kg chicken manure. Irrigation was done daily during a period in which

Table 1. Physical characteristics of Fluvic Neosol.

Physical Characteristics	Depth (m)			
	0-0.25	0.25-0.50	0.50- 0.75	0.75-1.00
Coarse Sand (kg kg ⁻¹) ¹	0.08	0.05	0.01	0.00
Fine Sand (kg kg ⁻¹) ¹	0.41	0.43	0.76	0.16
Silt (kg kg ⁻¹) ²	0.27	0.28	0.12	0.52
Clay (kg kg ⁻¹) ²	0.24	0.24	0.11	0.32
Bulk density (kg dm ⁻³) ³	1.62	1.38	1.34	1.31
Water content at -10 kPa (m ³ m ⁻³) ⁴	0.43	0.37	0.19	0.54
Water content at -1.500 kPa (m ³ m ⁻³) ⁴	0.15	0.12	0.05	0.16

¹ By screening; ² Pipette method; ³ Cylinder and the volumetric ring method; ⁴ Porous plate equipment.

the plant put out up to two vegetative flows. After flows were emitted, plants received the growth regulator Paclobutrazol. Irrigation was soon stopped and, when plants showed symptoms of epinasty of terminal branches (Mouco & Albuquerque, 2005), calcium nitrate was applied to leaves in order to break bud dormancy and induce uniform blooming.

RDI irrigation treatments were applied from blooming to fruit maturation, according to the three development phases described by Cotrim *et al.* (2011), Phase I being the time from the beginning of blooming (BB) to fruit set, generally around 65 days after BB. Phase II corresponds to the period of fruit expansion, generally up to 95 days after BB, and Phase III comprises growth cessation and physiological fruit maturation, which occurs around 120 days after BB. The different irrigation regimes (Table 2) studied were full irrigation (T1), three RDI schemes (T2, T3, and T4), and the no irrigation control (T5).

The differentiation among water depths obtained by irrigation with micro sprinklers was made possible by varying the duration of irrigation, stopping water delivery to each treatment when the desired depth had been obtained. Irrigation was performed based on reference evapotranspiration

determined daily by the method of Penman-Monteith (FAO's standard; Allen *et al.*, 1998), from data obtained at a nearby automatic weather station. Crop coefficients (K_c) employed for calculations of reference evapotranspiration during the evaluation phases of the experiment ranged from 0.45 to 0.85, as recommended by Silva *et al.* (2001), whereas the location coefficient was obtained with the method of Fereres, according to Bernando *et al.* (2006), for a unitary value.

Water depth applied to the different treatments is shown in Figure 1. They were applied from 10 to 115 and 136 days after blooming, during growth cycles one and two, respectively. After these dates no more irrigation was applied, since some rainfall occurred which supplied the crop's needs. Water for irrigation came from tubular wells and had an electrical conductivity which ranged from 0.62 to 1.32 dSm⁻¹.

Figure 2 shows the retention curves for the soils in the study. The layer situated from 0.5m to 0.75m, with a higher sand content (Table 1), is less water retentive, whereas the soil at 0.75 m to 1 m depth, with higher silt content, promotes increases water retention.

In order to study water distribution in the soil and to obtain data to trace the profiles of soil water extraction by the root system, TDR probes were set at one plant per treatment, and water content data were obtained from the beginning of Phase I to the end of Phase III. Probes were set so as to form a grid in the soil, making it possible to determine water contents 0.5 m, 1.0 m, 1.5 m, 2.0 m, and 2.5 m away from the trunk, in a longitudinal direction relative to the row of plants. At each distance point, probes were set 0.125 m, 0.375 m, 0.625 m, and 0.875 m depth.

Table 2. Description of the treatments of the irrigation regimes adopted in the experiment.

Treatment	% of ETc		
	Phase I	Phase II	Phase III
T1	100	100	100
T2	50	100	100
T3	100	50	100
T4	100	100	50
T5	0	0	0

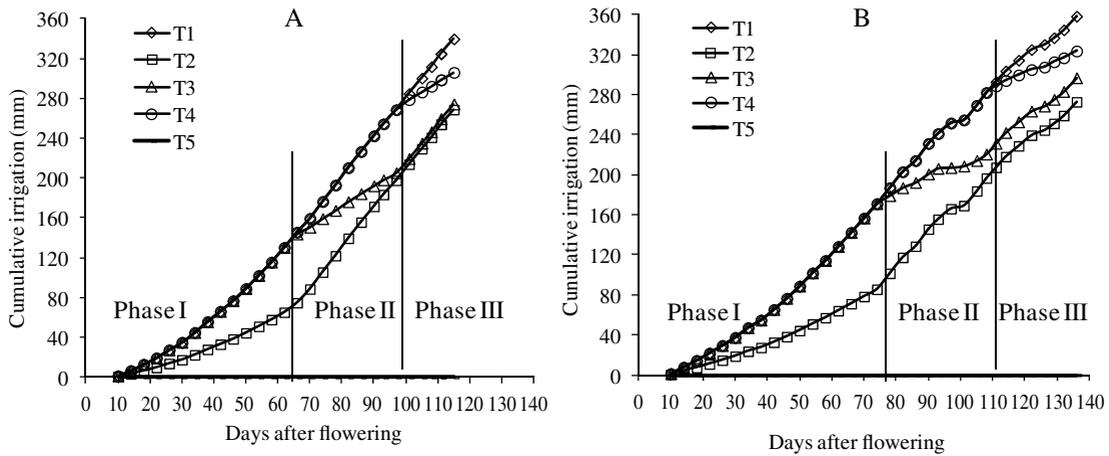


Figure 1. Cumulative irrigation applied in different treatments of RDI to 'Tommy Atkins' mangoes during the evaluation period. (A) first cycle and (B) second cycle.

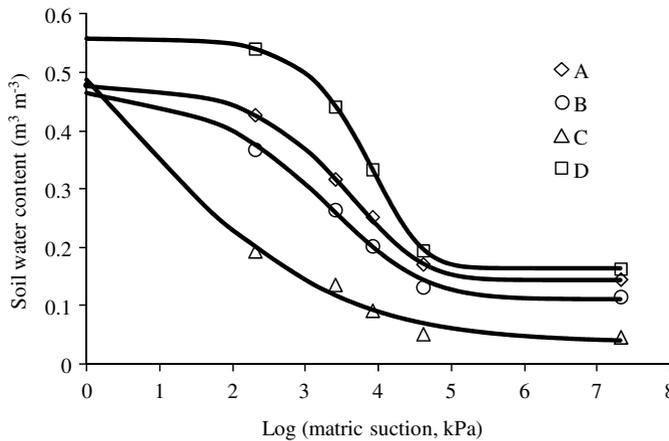


Figure 2. Soil-water characteristic curves: A (soil depth between 0.00 and 0.25 m), B (soil depth between 0.25 and 0.50 m), C (soil depth between 0.50 and 0,75 m) and D (soil depth between 0.75 and 1.00 m).

The TDR probes employed in this study were laboratory-made, and consisted of three 0.13 m-long rods, each with 0.10 m of effective length and 0.03 m covered by resin. Rods were spaced 1.7 cm apart and no resistor was used in the central rod (Silva *et al.*, 2005). Sensor calibration to determine water content was accomplished with a deformed soil sample, according to Santos *et al.* (2010), obtaining models to estimate water content (θ), on the basis of the dielectric constant (K_a), according to equations 1, 2, 3, and 4, for strata at depth 0 to 0.25 m, 0.25 to 0.5 m, 0.5 to 0.75 m, and 0.75 to 1.0 m, respectively.

$$\theta = 0.000023K_a^3 - 0.001474K_a^2 + 0.043010K_a - 0.256019, R^2 = 0.98 \quad (1)$$

$$\theta = 0.012121K_a - 0.059308, r^2 = 0.96 \quad (2)$$

$$\theta = 0.012230K_a - 0.066887, r^2 = 0.96 \quad (3)$$

$$\theta = 0.013641K_a - 0.059207, r^2 = 0.99 \quad (4)$$

Readings of soil water content were performed automatically, at 10 minute intervals, by coupling the probes to multiplexors, and those to a TDR which read and saved values of soil water content in a data logger.

The follow-up of average water content of the soil near the root system was done for one of the treatments with RDI and for the control. Due to a multiplexor limitation and to the distance between measured plants, follow-up was scheduled at 15 day intervals, so as to be able to observe the distribution of water content in the soil during cycle phase changes, when plants were to begin receiving a new depth of RDI.

The profile of water delivery ($\text{mm}\cdot\text{h}^{-1}$) by the micro sprinkler operating at 200 kPa, as well as the placements of the TDR probes and sprinklers relative to the trunk, can be verified in Figure 3. Calculations of water extraction by the roots were based on water contents determined at all points of the grid, at two time intervals, the first lasting from the end of irrigation to the end of the phase of severe reduction of water content (stage 1), and the other lasting from this point to the beginning of the next watering (stage 2; Figure 4), according to Coelho & Or (1997, 1999), and Silva *et al.* (2001).

Results and Discussion

The average daily measures of soil water content, for the different treatments taken at different points of the soil profile from the end of phase I to the beginning of phase III, are shown in Figure 5. Figure 5A shows data from treatments 1 through 5, 0.5 m away from the trunk and 0.125 m deep; in Figure 5B, data are from treatments 1, 2, 3, and 5, 0.625 m away from the trunk.

At all depths water content in treatment 5 (no irrigation) remained near $-1,500$ kPa (Table 1).

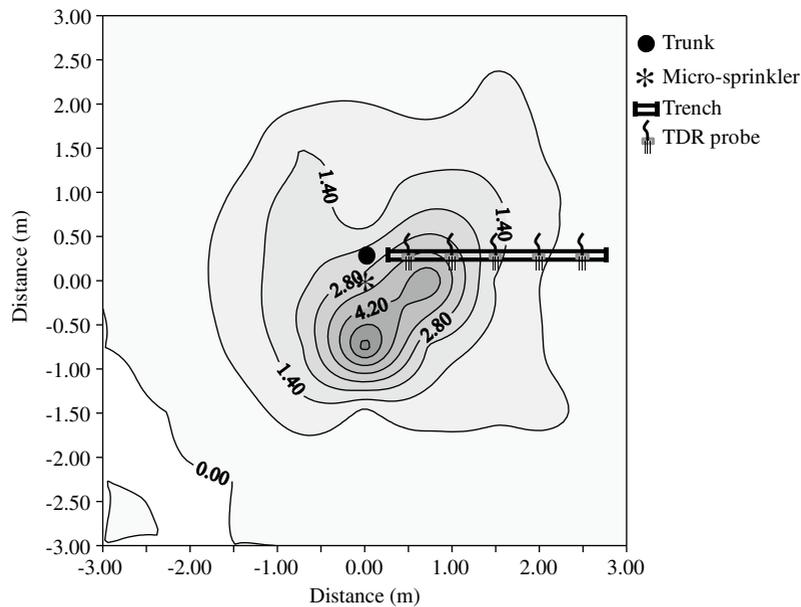


Figure 3. Profile of water application intensity ($\text{mm}\cdot\text{h}^{-1}$) by the micro-sprinkler, placements of the TDR probes, micro-sprinklers and position of the mango tree.

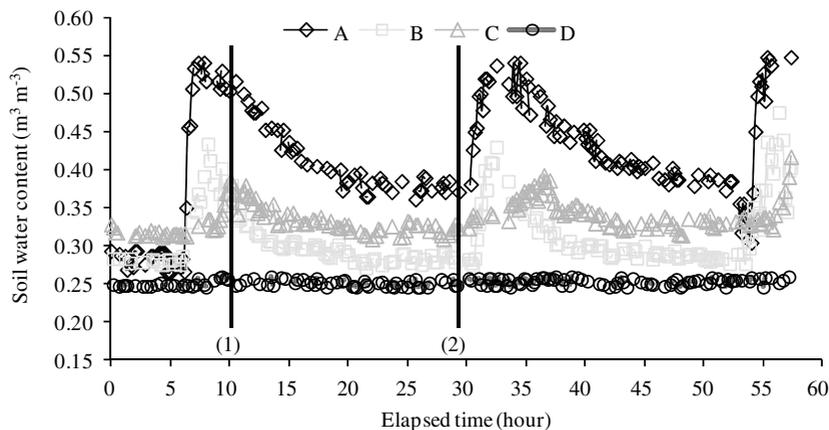


Figure 4. Soil water content in depths: 0.125 m (A); 0.375 m (B); 0.625 m (C) e 0.875 m (D) after the end irrigation (1) and before next irrigation (2).

This makes it evident that there was no interference from water sources near the root system. On the other hand, water content of the other treatments at the surface layer and 0.5 m away from the trunk varied accordingly, and at a depth of 0.625 m, 0.5 m away from the trunk, treatment 2 presented the lowest measures of water content during the first 75 days after blooming, increasing gradually from this point on. Since RDI with 50% ETC was done during phase I, increasing to 100% ETC at subsequent phases, these variations were to be expected. Watering with 100% ETC contributed to increase the advance of the wetting front into deeper layers of the soil. The opposite behavior is

observed for treatment 3 (Figure 5D), where soil water content decreased after 80 days after blooming on the third layer, 0.625 m deep and 1.5 m away from the trunk. Treatment 3 received full irrigation during phase I and was changed to RDI with 50% ETC during phase II, which explains the decreases in soil water content observed.

Soil water content at the surface 2.0 m away from the trunk (Figure 5E), measured for all treatments with irrigation varied little, as a consequence of the fact that the reach of the water spray is restricted to a radius of 2.5 m from the emitter (Figure 3). When measured 2.5 m away from the trunk and at a depth of 0.625 m, water contents (Figure 5F)

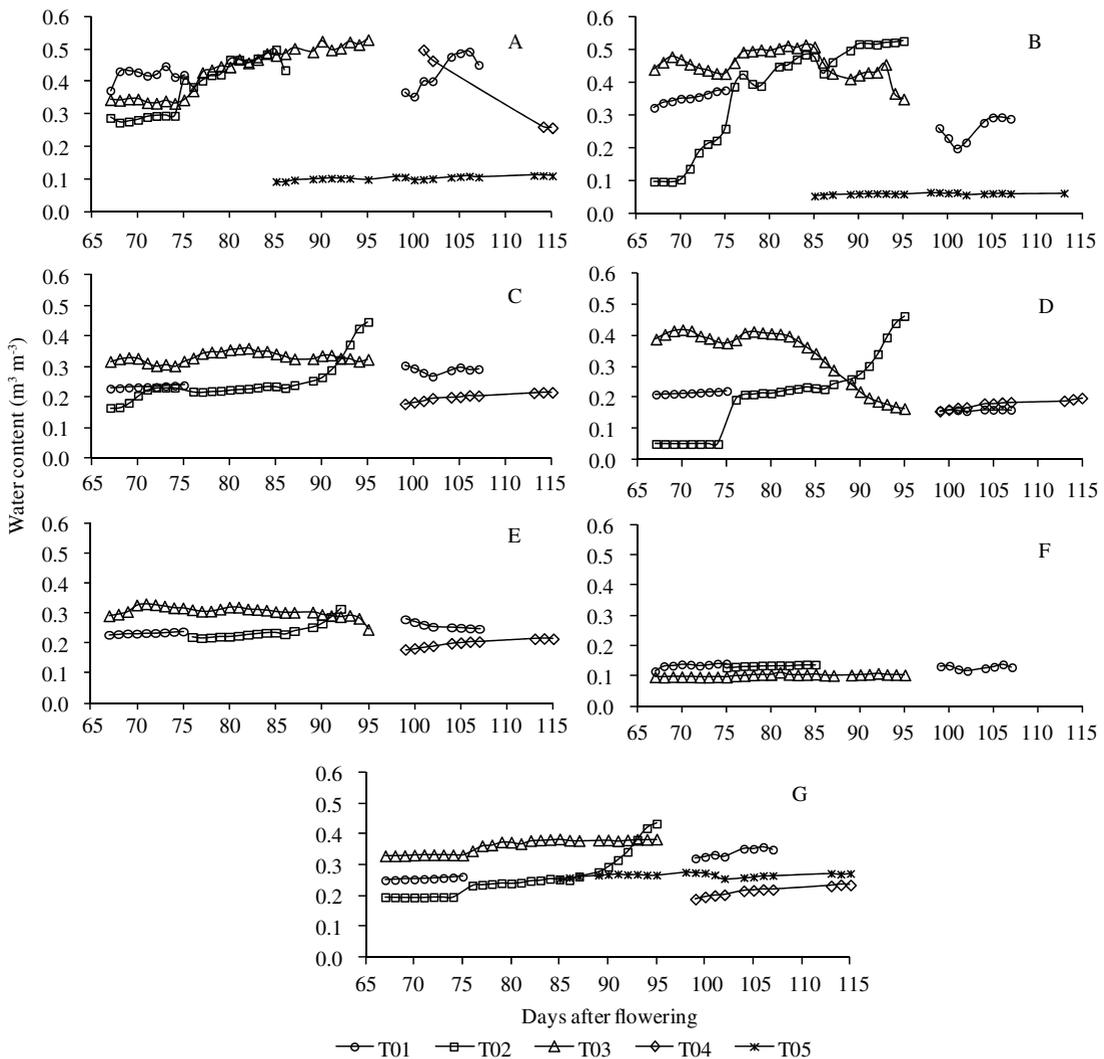


Figure 5. Soil water content in the different treatments: 0.50 from the trunk and 0.125 m depth (A); 0.50 m from the trunk and 0.625 m depth (B); 1.50 m from the trunk and 0.125 m depth (C); 1.50 m from the trunk and 0.625 m depth (D); 2.00 m from the trunk and 0.125 m depth (E); 2.50 m from the trunk and 0.625 m depth (F) 1.50 to 2.00 m from the trunk and 0.875 m depth (G).

averaged near -30 kPa. This is compatible with the elevated contents of silt and clay observed between the 0.75 m and 1.0 m layers, which reduce water percolation, in contrast to the sandy layer observed at depths between 0.5 m and 0.75 m. The lower clay layers force water to accumulate in the sandy layer and promote its horizontal distribution, reaching 2.5 m away from the trunk.

The values of water content for treatments 1, 2, and 4 were similar to those observed under non-irrigated conditions (treatment 5) at the depth of 0.875 m (Figure 5G). For treatments 3 and 1, water content reached values around $0.4 \text{ m}^3 \text{ m}^{-3}$. These data confirm that, when water management is adequate there is no deep percolation, since water content at -10 kPa, for this layer, was $0.54 \text{ m}^3 \text{ m}^{-3}$ (Table 1), and water contents under monitored conditions did not reach this limit.

Figure 6 shows the isolines of soil water content before and after irrigation for treatment 1. Despite

the ability of the microsprinkler jet to reach a radius slightly greater than 2.5 m (Figure 3), the greatest contribution in terms of wet area remains within the first 1.5 m away from the trunk, increasing water content values in the soil profile at this distance.

In the case of treatments 2 and 3 (Figures 7 and 8, respectively), the isolines of water content in the soil profile take into account measurements from two distinct phases of the growth cycle, one during fruit set, when treatment 2 received RDI with 50% ETC and treatment 3 received full irrigation, and the other during the phase of fruit expansion, when treatment 2 received full irrigation and treatment 3 received RDI with 50% ETC. In both cases the influence of RDI on the wet profile of the soil could be observed, both before and after irrigation; there was an increase in the wetting front when irrigation of treatment 2 was switched from RDI with 50% to 100% ETC, and a reduction in the wet profile of treatment 3 when irrigation was switched to RDI.

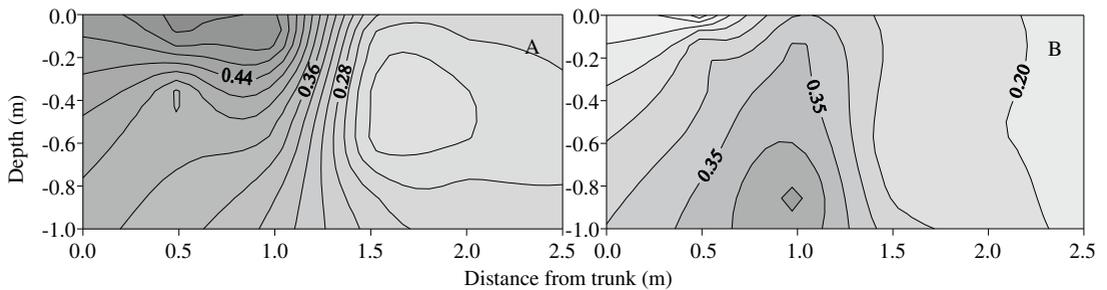


Figure 6. Isolines of soil water content ($\text{m}^3 \text{ m}^{-3}$) for treatment 1 after of the irrigation (A) and before irrigation (B) in the phase I of the 'Tommy Atkins'.

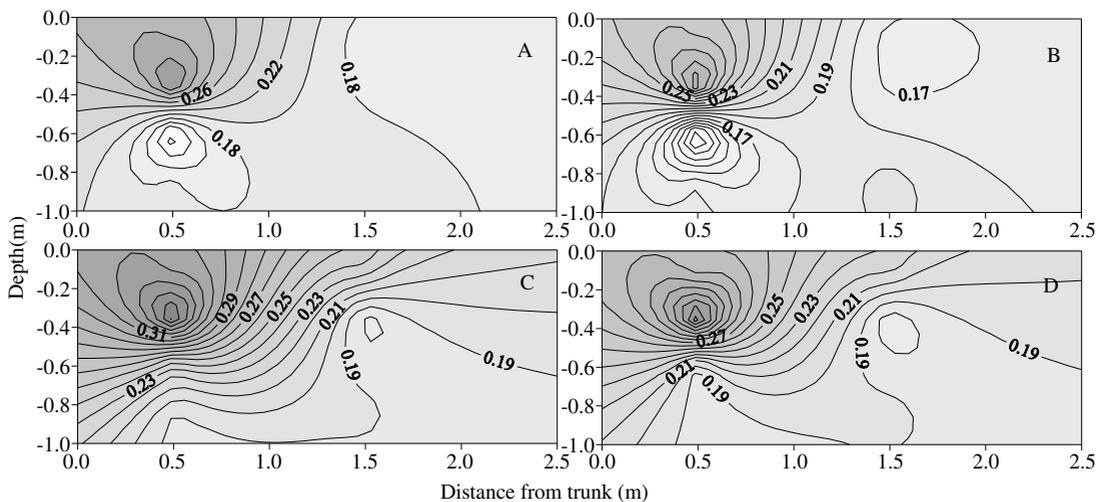


Figure 7. Isolines of soil water content ($\text{m}^3 \text{ m}^{-3}$) for treatment 2, after irrigation in phase I (A), before irrigation in phase I (B), after irrigation in phase II (C) and before irrigation in phase II (D) of the 'Tommy Atkins'.

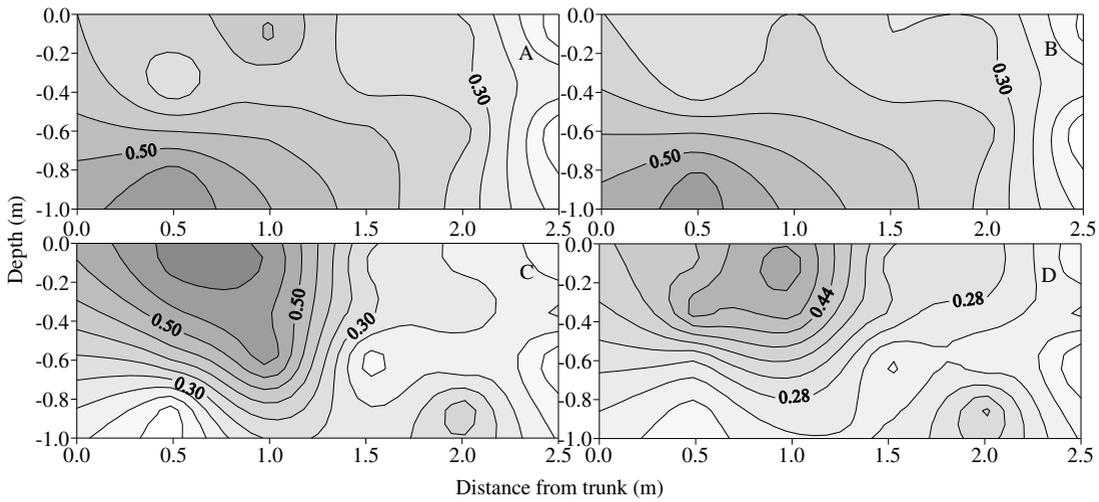


Figure 8. Isolines of soil water content ($\text{m}^3 \text{m}^{-3}$) for treatment 3, after irrigation in phase I (A), before irrigation in phase I (B), after irrigation in phase II (C) and before irrigation in phase II (D) of the ‘Tommy Atkins’.

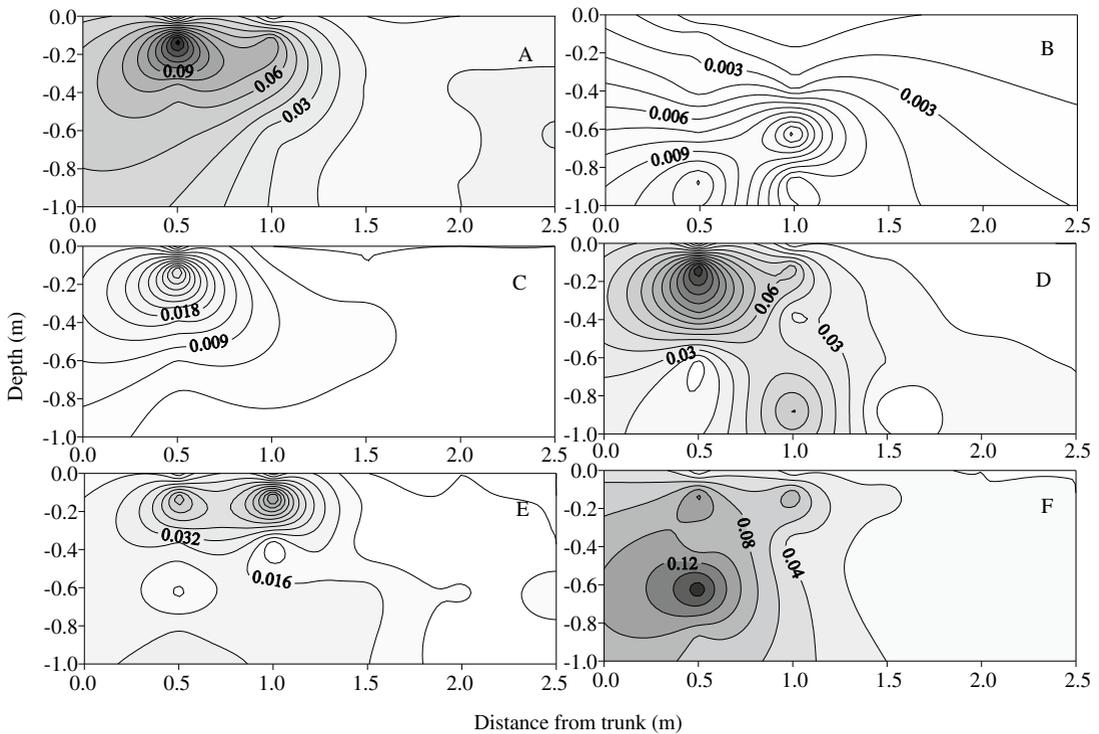


Figure 9. Isolines of soil water extraction ($\text{m}^3 \text{m}^{-3}$) by root system of the ‘Tommy Atkins’ for treatment 1 in phase I (A), treatment 5 (B), treatment 2 in phase I (C), treatment 2 in phase II (D), treatment 3 in phase I (E), treatment 3 in phase II (F).

Water extraction by the plant for all treatments, can be observed in Figure 9, whereas the average soil water content at a depth of 0.875 m for treatments 1, 2, and 3 can be observed in Figure 10. It is worth stressing that no percolation was observed, since

variations in the soil water content were minimum from one hour to 17 hours after irrigation ceased (Figure 10).

In the case of treatment 5 (Figure 9B), water extraction was estimated over a 15-day period, since

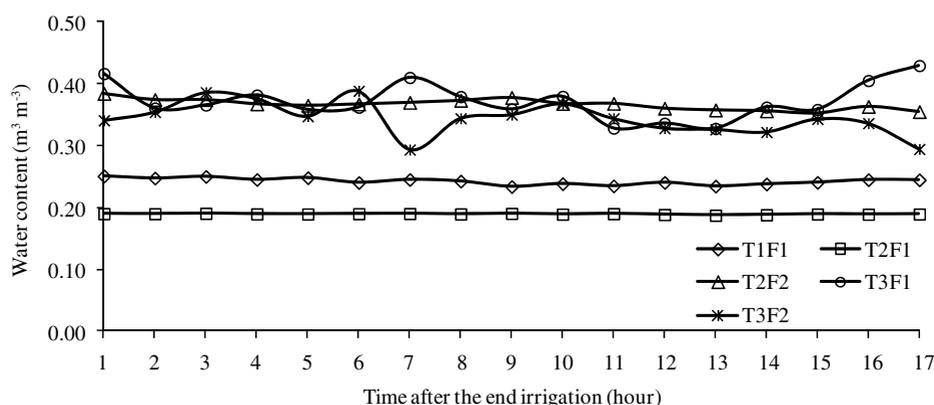


Figure 10. Soil water content ($\text{m}^3 \text{m}^{-3}$) 0.875 m depth for treatment 1 in phase I (T1F1), treatment 2 in phase I (T2F1), treatment 2 in phase II (T2F2), treatment 3 in phase I (T3F1) and treatment 3 in phase II (T3F2) applied on 'Tommy Atkins'.

the plants received no irrigation and the decrease in moisture varies very little on a daily basis. It may be observed from the isolines that water extraction values are much reduced, even when differences in moisture over an extended period are taken into account. This is an expected behavior, since plants were not irrigated. Water extraction occurs mostly from the deepest layers of the soil (Figures 9D, 9F).

It is also observed that water extraction is more pronounced at a distance less than 1.5 m from the trunk in the soil profile, and within the first 0.5 m of soil depth in treatment 1 (Figure 9A) and phase I of treatments 2 and 3 (Figures 9C and 9E, respectively). Soil water extraction, considered after a period of alteration of the irrigation sheet as in treatment 2 (Figure 9D) and treatment 3 (Figure 9F) during phase II, was more intense in the deeper layers of the soil compared to extraction during phase I. In the case of treatment 2 during phase II, this behavior can be attributed to the increase in irrigation, whereas in the case of treatment 3 it was due to the fact that the difference between soil water contents after irrigation and before the next irrigation was greater than in the superficial layers, as a result of the decrease in the water content from the deepest to the more superficial layers which, in turn, resulted from the reduction from full irrigation to RDI with 50% ETC.

The evaluation of the spatial distribution and water absorption by the root systems of Haden mango trees receiving sprinkler irrigation performed by Santos (1997) demonstrated that 75.58% of water

extraction by the plant occurs within a distance of 1.5 m from the trunk and a depth of 0.8 m in the soil profile. When we take in to account the consumption of soil solution, considering a distance of 2.0 m from the trunk, 48.36% occurred between 0 to 0.2 m depth, 20% from 0.2 m to 0.4 m depth, 9.6% from 0.4 m to 0.6 m depth and 13% from the layers from 0.6 to 0.8 m depth.

Conclusions

1. The profiles of water distribution in the soil are influenced by the irrigation regimen adopted.
2. Soil water extraction does not depend on the treatment and is most intense up to 1.5 m away from the trunk, and within the first 0.5 m of soil depth.
3. After alterations in the amount of water employed for irrigation, water extraction is intensified in the deepest soil layers.
4. TDR is an effective technique to study soil water distribution and water extraction by agricultural crops.

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