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Irrigation of papaya in a sandy loam soil in the semiarid of Bahia, Brazil

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ABSTRACT: Irrigated farming enables producing papaya in Iaçu, located in the semiarid region of Bahia. However, water must be used efficiently, as the local availability of irrigation water resources is restricted. This study was conducted with the objective of defining the irrigation depth that provides the best agronomic performance of the Tainung No. 1 papaya cultivar, in a sandy loam soil of Iaçu, in the semiarid of Bahia, under the irrigation management conditions adopted by the producer. The experimental design used was of randomized blocks with four replicates. The experimental plot consisted of a row of plants, containing two border plants and twelve useful plants. Treatments corresponded to the total water depth of 1.103; 1.702; 2226; 2.751; 3.349 mm. Studied variables were height, leaf area, fruit number and yield, water use efficiency, fruit weight, fruit diameter and length, pulp width, pulp water content, pH, soluble solids and titratable acidity. Growth and production of the papaya tree responded positively to the applied water depths, but there was no interference in fruit quality. The yield showed linear adjustment, with a calculated maximum at 123.845 t ha^{-1} obtained for 3.349 mm. With the increasing water depth applied, there was a reduction in water use efficiency due to percolation water loss.

Key words: *Carica papaya* L.; deep percolation; irrigation scheduling; waste of water in irrigation; water use efficiency

Irrigação do mamoeiro em um solo franco arenoso no semiárido baiano, Brasil

RESUMO: O cultivo irrigado possibilita a produção de mamão em Iaçu, no semiárido baiano. Contudo, a água deve ser utilizada de forma eficiente, pois a disponibilidade local de recursos hídricos para irrigação é restrita. O trabalho foi realizado com o objetivo de definir a lâmina de irrigação que proporciona o melhor desempenho agronômico do mamoeiro cultivar Tainung nº 1, em um solo franco arenoso de Iaçu, no semiárido baiano, nas condições de manejo de irrigação adotadas pelo produtor. O delineamento experimental foi em blocos casualizados com quatro repetições. A parcela experimental foi composta por uma fileira de plantas contendo duas plantas de bordadura e doze plantas úteis. Os tratamentos corresponderam às lâminas totais de água de 1.103; 1.702; 2226; 2.751; 3.349 mm. As variáveis estudadas foram: altura, área foliar, número e produtividade de frutos, eficiência de uso de água, massa do fruto, diâmetro e comprimento do fruto, espessura da polpa, teor de umidade da polpa, pH, sólidos solúveis e acidez titulável. O crescimento e produção do mamoeiro responderam positivamente as lâminas de água aplicadas, mas não houve interferência na qualidade dos frutos. A produtividade apresentou ajuste linear, com máxima produtividade calculada em 123,845 t ha^{-1} obtida para lâmina de 3.349 mm. Na medida em que houve acréscimo da lâmina de água aplicada houve redução da eficiência no uso da água em função das perdas de água por percolação.

Palavras-chave: *Carica papaya* L.; percolação profunda; manejo de irrigação; desperdício de água; eficiência no uso da água

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Introduction

Brazil is one of the five largest papaya producers in the world, with this position reflecting the appropriate climate conditions and cultivars with high production potential throughout the year (Luz et al., 2015; Lucena, 2016).

Papaya orchards have high needs for water and nutrients all along its production cycle, as the plants show vigorous vegetative growth until the reproductive phase, when the demands are potentiated due to the continuous production of flowers and fruit (Campostrini & Gleen, 2007; Coelho et al., 2011; Anjos et al., 2015).

In regions with water deficit problems, it is necessary to irrigate the papaya (Coelho et al., 2011; Mendonça, 2017). Notably, in production complexes located in the semiarid region, since the yield damage tends to be more severe due to the crop sensitivity to the association of stresses from abiotic nature (Campostrini et al., 2018).

In contrast, the semiarid region has favorable edaphoclimatic conditions for the crop irrigated cultivation (Santos et al., 2008; Anjos et al., 2015; Feitosa et al., 2016; Feitosa et al., 2018), including the reduction in the incidence of fungal diseases related to high relative humidity (Lucena, 2016).

The limiting factor for irrigation in the semiarid region is the water resources scarcity for said activity, resulting mainly from the negative water balance, on the exploitation of surface water sources and the groundwater quality, which often has a high content of dissolved salts (Pereira & Cuellar, 2015; Neves et al., 2017).

In this context of restricted water supply, the need of adjusting the irrigation planning and management gains a greater notoriety and sympathy from the producers, who see the reduction of water waste as an opportunity to increase profitability due to cost reduction and the expansion possibility of the irrigated area (Almeida et al., 2004; Frizzone, 2007).

Irrigation management must be adapted in order to prioritize efficiency in the use of water while focusing on the orchard economic performance. Thereby, it becomes necessary to adapt the irrigation practice to the water availability, soil type, cultivation needs and to adopt management techniques that mitigate water losses through evaporation and percolation (Coelho et al., 2011; Santoro et al., 2013; Franco et al., 2017). Moreover, it is important to choose productive cultivars that tolerate the semi-arid climate and are responsive to irrigation, such as the Tainung No. 1 cultivar (Silva et al., 2001; Garcia et al., 2007; Santos et al., 2008; Luz et al., 2015).

This study aimed to define the irrigation depth that provides the best agronomic performance of the Tainung No. 1 papaya cultivar, in a sandy loam soil of Iaçu, in the semiarid region of Bahia, under the conditions of irrigation management adopted by the producer.

Materials and Methods

This research was developed in partnership with Boa Vista Farm, which belongs to the group Iaçu Agropastoril Ltda.

Experimental activities were conducted between October 2012 and October 2013. The property is located in the municipality of Iaçu, in the semiarid region of Bahia. The experimental area is located at an altitude of 280 m, at the geographical coordinates of 12°34'00" South latitude and 39°59'57" West longitude. The local climate is classified as BSh according to the classification by Köppen and Geiger (Álvares et al., 2013).

The experimental area soil was classified as a Haplic Dystrophic Planosol (Santos et al., 2018). Granulometric analysis revealed the loamy sandy soil nature of the soil, with 750 g kg^{-1} of total sand, 97 g kg^{-1} of silt and 152.5 g kg^{-1} of clay. The volumetric humidity obtained for stresses 6, 10, 30, 100, 300, 1500 KPa were: 0.1396; 0.1247; 0.1057; 0.0852; 0.0785; 0.0729 cm^3 cm^{-3}, for the soil layer between 0 and 0.2 m, and 0.1754; 0.1754; 0.1436; 0.1272; 0.1101; 0.1052 cm cm^{-3}, for the soil layer between 0.2 and 0.4 m deep. Available water for the 0 to 0.2 and from 0.2 to 0.4 m layers was calculated as 10.36 and 14.04 mm, respectively. Hydro-physical analyzes were conducted by using similar methods to those described by Teixeira et al. (2017).

The experiment was conducted during the first production year of a commercial orchard with the papaya (*Carica papaya* L.) cultivar Tainung No. 1, set up at a spacing of 4 x 2 m (1,250 plants ha^{-1}). At the planting, seedlings obtained from seeds of approximately 0.15 m in length were used.

Liming and nutrient requirements were calculated according to the result of the soil analysis and the expected yield, as recommended by Oliveira et al. (2004). Liming was held by applying dolomitic limestone, in order to raise the base saturation to 70%. Planting fertilization was carried out by pit, with the application of 60 kg of N ha^{-1}, in the bovine manure form and 200 kg of P$_2$O$_5$ ha^{-1}, in the simple superphosphate form. Topdressing fertilization was applied by fertigation, every fifteen days. From 30 to 120 days after planting (DAP), 7.5 kg of N in the urea form and 10 kg of K$_2$O in the potassium chloride form were applied. From the flowering onwards, at 135 DAP, 17.5 kg of N ha^{-1} and 20 kg of K$_2$O were applied in potassium chloride form.

The experimental design was a randomized block with four replicates. The experimental plot consisted in a row of plants containing two border plants and twelve useful plants. The treatments corresponded to total applied water depths (TWD) of 1,103; 1,702; 2226; 2,751; 3,349 mm and they were applied from 40 DAP on.

The TWD was obtained by summing up the total irrigation depth applied (TID) and the effective precipitation accumulated in the 505 mm period. TID was differentiated by means of a set of self-compensating drippers of 8, 16, 23, 30 and 38 L h^{-1} plant^{-1}. The same number of water emission points per plant was maintained. The service pressure was maintained above 1 kgf cm^{-2} during the irrigation events, with lateral lines less than 60 m long. The irrigation frequency was daily and its system operating time was the same for all treatments. The adopted method for estimating effective precipitation was that of the United States Soil Conservation Service (Bernardo et al., 2005).

Gross irrigation depth was found by the product of the flow from the set of emitters by the irrigation time. Liquid depth was calculated considering the irrigation efficiency of 90% and the wet area (Coelho et al., 2011). Reference evapotranspiration was obtained by the Penman-Monteith equation, as presented by Allen et al. (1998) and the accumulated reference evapotranspiration in the period was of 1,804 mm. Means of relative humidity, average temperature and reference evapotranspiration recorded during the experiment are displayed in figure 1.

Soil moisture was monitored with a soil moisture analyzer that worked using the principle of time domain reflectometry (TDR). Soil moisture was recorded weekly before the irrigation events, by using readings from a TDR probe set up at the 0.20 and 0.40 m depths. They were set up in one plant per plot, away 0.25 m from the plant and 0.15 m from the emitter line.

Plant height and leaf area were evaluated at 320 DAP, in the last harvest. The height was measured with a flexible ruler, from the root collar of the plant to its apical bud, and the leaf area was by using the methodology described by Souza et al. (2005).

Harvesting started in the seventh month after planting. The number of commercial fruit and the orchard yield were evaluated. Efficiency of water use was determined by the ratio between yield and the total water volume applied per plant. Additionally, it was also calculated how much water was spent to produce each fruit with commercial characteristics.

At 12 months after planting, three fruit were randomly picked from each useful plant, totaling 120 fruit per treatment, aiming to evaluate the fruit quality in terms of their physical and chemical characteristics (Souza et al., 2009). The analyzes consisted of measuring the fruit diameter and longitudinal length, thickness of its pulp, moisture content, pH, titratable acidity and total soluble solids. Fruit were analyzed at the maturation stage 4, when they had between 50 and 75% of their peel as orange (MAPA, 2010).

Measures of diameter, height and thickness of the fruit pulp were performed with a Digimess digital caliper.

Gravimetric humidity was determined by using a semi-analytical balance. Content of soluble solids in the filtered pulp was found by direct reading on refractometers. The pH was determined by direct reading on the crushed pulp, by using a portable pH reader. Titratable acidity was found from the titration of a solution containing five grams of pulp in 0.1 N sodium hydroxide solution having phenolphthalein as an indicator (AOAC, 1990).

Analysis of variance was performed at 5% probability. From the F test result, data regression analysis was performed in order to identify the fittings occurrence to the tested mathematical models (Banzatto & Kronka, 1995). Statistical analyzes were performed supported by the SISVAR software, version 5.6 (Ferreira, 2011). Relative means comparisons were held between the highest and lowest means of the variables that were influenced by the treatments.

Results and Discussion

From the height and leaf area evaluations of the plants subjected to different irrigation depths, the data displayed in Figure 2 were obtained. These results indicate that the TWD increase provided an increase in height and leaf area, with linear fitting for both variables.

Plants that received the highest water supply (TWD: 1,103 mm) had height and leaf area of 34.70 and 62.46% higher than the ones that received the lowest water supply (TWD: 3,349 mm).

According to Coelho et al. (2011), the leaf area is one of the papaya tree growth variables that is most sensitive to the water availability in the soil. Height, on the other hand, is less sensitive. The same authors studied the growth of 'Tainung No. 1' in the semiarid conditions of Iaçu, under irrigation, and found values close to the recorded in this study.

Recorded differences in vigor reflect the water availability that papaya plants had access. A similar behavior was verified for the number of fruit and papaya tree yield, which showed
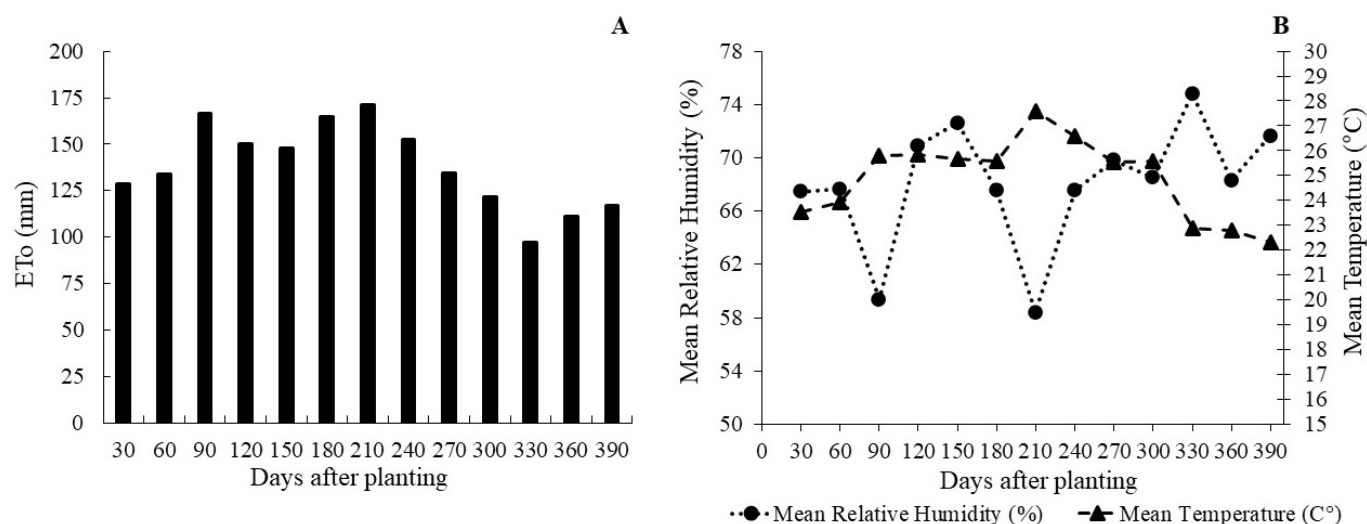

Figure 1. ETO: reference evapotranspiration (A), relative humidity and mean air temperature (B), recorded during the experiment, in function of the time, in days after planting (DAP).
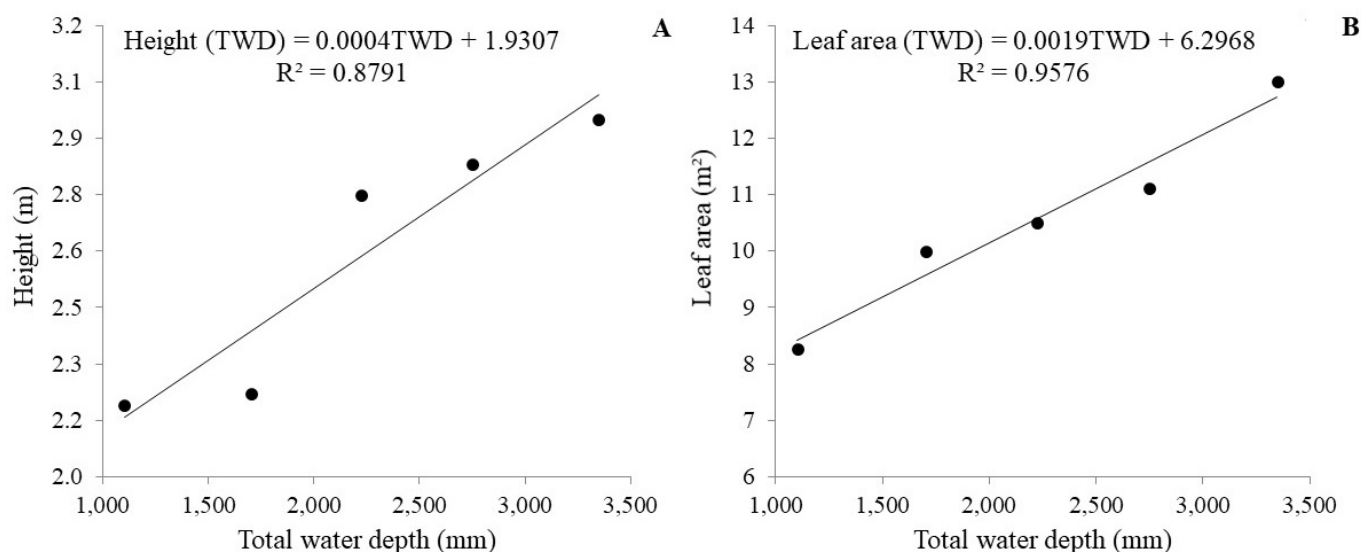
Figure 2. Height (A) and leaf area (B) of papaya tree at 320 DAP, in function of the total water depth applied (TWD).

fittings to the quadratic and linear models, respectively (Figure 3).

From the regression equations, the TWD that provided the largest number of fruit, 100,788 fruit ha^{-1}, was found to be in the order of 3,019 mm. The applied 3,349 mm TWD provided the highest yield, 123,846 t ha^{-1}. When relatively comparing the highest values with those of the lowest means from each TWD, an increase of 65.99% in the number of fruit and 71.32% for yield was observed (Table 1).

When examining the recorded means of the number of fruit and yield for each depth, it is important to note that the rising yield had the increase in fruit weight as its origin, since there is little difference between the numbers of fruit from 2,226 mm TWD.

Usually, papaya is traded on a unit basis by both producers and marketers alike. Negotiation of the fruit by its weight is more common for supply contracts and distribution centers, aimed

Table 1. Result of the Scott-Knott mean test for the observed means from the number of fruit and yield.

TWD (mm)	Number of fruit (fruit ha^{-1})	Yield (t ha^{-1})
1.103	60.192	67.847
1.702	78.859	87.338
2.226	97.031	104.655
2.751	98.253	116.239
3.349	99.914	116.149
CV (%)	27.38	22.29

TWD: Total water depth applied.

at commercialization with the final consumer. Commercial fruit of 'Tainung No. 1' papaya generally have weight variations between 0.80 kg and 1.10 kg (Costa & Pacova, 2003). In terms of commercial classification, the evaluated fruit were between categories J and K that stands for fruit with weight between 0.80 and 1.30 kg (CEAGESP, 2003).
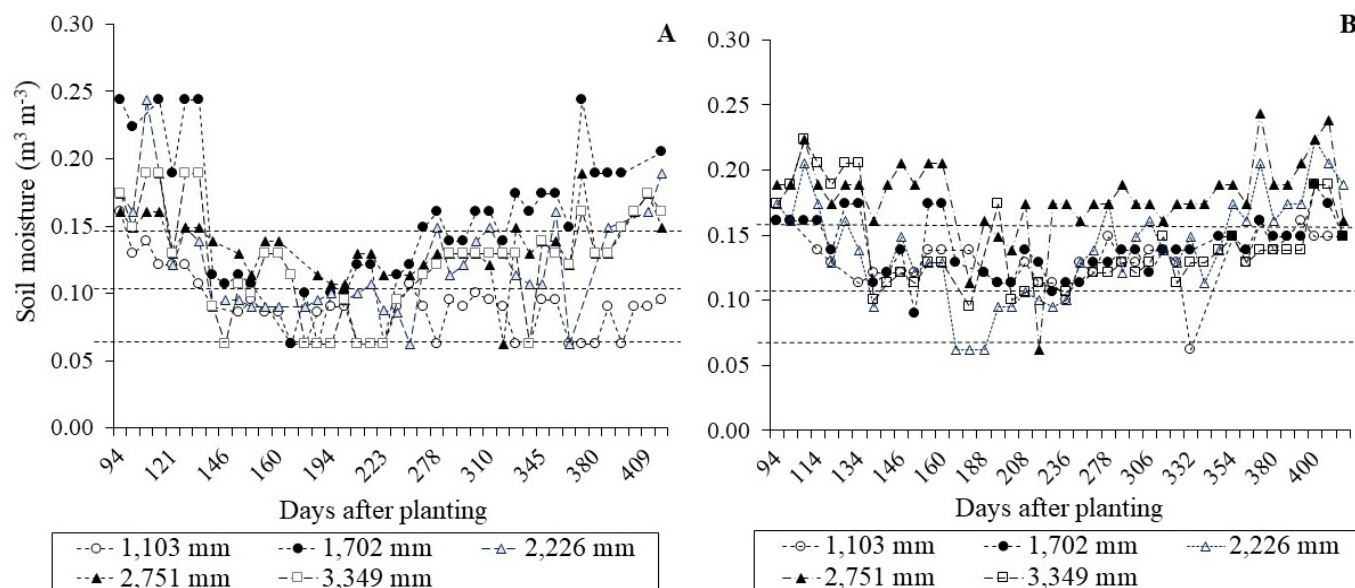

Figure 3. Accumulated number of harvested fruit (A) and yield (B), until 320 DAP, in function of the total water depth applied (TWD).

Yield results verified in the present study were inferior when compared to the results published by Santos et al. (2008), who evaluated the response of 'Tainung No. 1' to the application of different water depths, in a soil with a sandy loam texture, in the Ceará Semiarid. These authors identified a linear fitting of yield as a function of TWD, with a maximum depth calculated for replacing 150% of the A class tank evaporation and maximum yield just over 150 t ha^{-1}. Other authors have also identified a linear fitting in the relatio between yield and TWD under different soil and climate conditions (Silva et al., 2001; Garcia et al., 2007; Coelho et al., 2010).

The low increase in the number of fruit and yield per applied unit of water, starting with depths of 2,226 and 2,751 mm, respectively, are justified because in these water supply conditions, the upper limit of water availability in the soil was often reached (Figure 4). Especially in the soil layer between 0.20 – 0.40 m, which implied the percolation of the excess water to deeper soil layers, far from the papaya roots zone of effect.

Irrigation regimes with TWD of 2,751 and 3,349 mm had the highest number of evaluations (45% of the total) with humidity above 100% of the available soil water. TWD regimes of 1,702 and 2,226 mm provided available water above 100% in 22% of the evaluations. Only for the irrigation regime referring to the 1,103 mm TWD, there was no record of water available above 100% during the evaluations. These results show the occurrence of water losses through percolation and explain the decrease in the water use efficiency with the rising TWD (Figure 5).
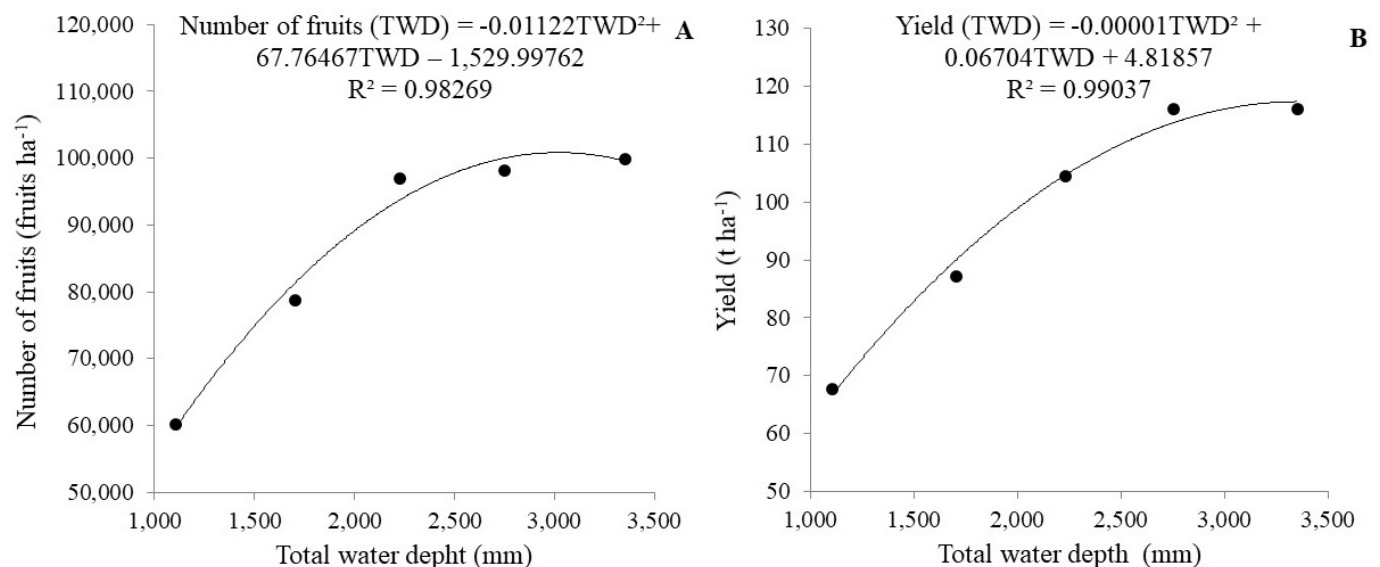

Figure 4. Moisture in the soil through the crop cycle of the Tainung No. 1 papaya at the depths of (A) 0-0,20 m and (B) 0,20 – 0,40 m. Dashed line above the field capacity (field cap), the lower the permanent wilt point (PWP) and the intermediate 50% of the available soil water.
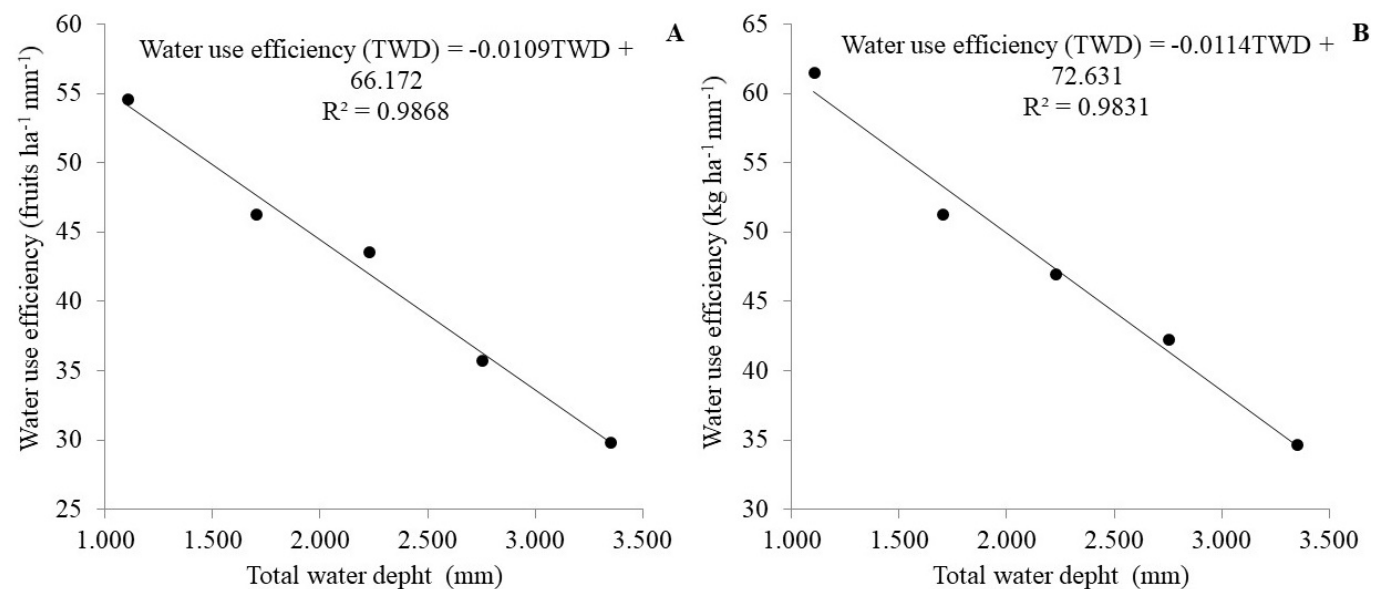

Figure 5. Water usage efficiency in terms of number of fruit (A) yield (B) in function of the total water depth applied (TWD).

Loss of water to soil layers beyond the root system effective depth reflects the inefficient use of water and possible nutrient ions losses by leaching. In soils with high sand content, such as those with a sandy loam texture, water and nutrient losses can be even greater due to the low water-holding and cationic exchange capacity of the soil (Santoro et al., 2013; Franco et al ., 2017).

In this study scenario, adopting irrigation management practices that control water losses are even more important, as water waste plays a prominent role in the Semiarid, since availability of water resources for irrigation is more restricted in this region, and the expansion of the irrigated area is one of the most limiting factors (Pereira & Cuellar, 2015; Neves et al., 2017).

Adopting the depth that maximizes yield or the number of fruit is not a reasonable option in the context of efficient use of water resources, as in present study. Especially, when there is little difference between the obtained results with the application of lower water depths and there is no effect of the TWD decrease on the physical-chemical quality of papaya (Table 2). It is added that the means of the physical-chemical quality variables of the fruit of the present study are close to those disclosed by Souza et al. (2009) and Silva et al. (2015).

Therefore, making a thorough economic assessment of the activity is essential, in order to establish, with a satisfactory confidence level, the water depth that can provide greater profitability per applied unit of water with an acceptable risk of failure by the producer (Almeida et al., 2004; Frizzone, 2007; Feitosa et al. 2018).

It is noteworthy that the results of this study corroborate to the recommendations made in the most basic irrigation studies, with regard to the need of adjusting the practice of irrigation, aiming at the rational use of water (Bernardo et al., 2005).

Better results could have been attained by implementing practices such as increasing the frequency of water application, adjusting the irrigation depth and monitoring percolation. By adopting these management practices, there would be a shift in the range of water availability in the soil to higher values, for a longer time and with less or even zero percolation losses, with positive effects on the efficiency of water use and, consequently, in the profitability per applied unit of water.

Conclusions

The increase in irrigation depth stimulated the agronomic performance of the 'Tainung No. 1' papaya tree;

The highest calculated yield, 123.846 t ha^{-1}, was found by the application of the total water depth applied of 3,349 mm.

Physical-chemical quality of papaya fruit was not influenced by the irrigation depths.

The efficiency in the water use dropped with the increase of the irrigation depth due to the water losses through percolation.

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Table 2. Means of the physical and chemical attributes of the papaya fruit sorted by the total water depth applied.

TWD (mm)	Fruit height	Fruit diameter	Fruit weight (g)	Pulp thickness (cm)	pH (Dimensionless)	Soluble solids	Titrable acidity	Fruit moisture
	(cm)						(%)	
1.103	21.900	9.689	989.750	2.555	5.437	12.800	0.082	87.940
1.702	22.167	10.481	1173.953	2.571	5.337	12.800	0.077	88.030
2.226	20.733	10.110	979.967	2.421	5.396	11.333	0.074	89.560
2.751	20.500	9.434	820.730	2.105	5.492	10.667	0.071	88.850
3.349	21.700	10.285	1105.197	2.401	5.137	9.000	0.078	89.670
Mean	21.400	10.001	1013.919	2.411	5.360	11.320	0.077	88.810

TWD: Total water depth applied.

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