WATER REQUIREMENT AND YIELD OF FIG TREES UNDER DIFFERENT DRIP IRRIGATION MANAGEMENT[1]

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ABSTRACT: This work aimed to study the effect of drip irrigation management on growth and yield of the 'Roxo de Valinhos' fig tree (*Ficus carica* L.), at three years old, and to determine crop coefficients (Kc) and its water requirement (ETc) under Baixada Fluminense climate and soil conditions, state of Rio de Janeiro, Brazil. The study was carried out in the experimental area of SIPA (Sistema Integrado de Produção Agroecológica) in Seropédica, Rio de Janeiro State, from July 2011 to May 2012. The experimental area was divided in two blocks, named B1 (sandy clay loam texture) and B2 (loamy sand texture). In each block, irrigation frequencies (IF) of two (T1) and four days (T2) were evaluated, as well as the irrigation absence (T3). Irrigation management and water consumption determination were performed through the soil water balance, using the TDR technique. Plant growth was not affected by IF, differing only in the number of produced internodes. For both soil textures, the mean Kc was 0.60, with a significant difference ($p \leq 0.05$) only for IF. The estimated mean yield showed no significant differences between both textural classes, ranging from 6,612 kg ha^{-1} (T3) to 8,554 kg ha^{-1} (T1). This study indicates the importance of irrigation frequency in the irrigation management of fig trees cultivated in soils with different physical characteristics.

KEYWORDS: Crop coefficient, *Ficus carica* L., TDR, irrigation frequency, water balance.

CONSUMO HÍDRICO E DESEMPENHO AGRONÔMICO DA FIGUEIRA SOB DIFERENTES MANEJOS DA IRRIGAÇÃO POR GOTEJAMENTO

RESUMO: Este trabalho teve como objetivo estudar o efeito do manejo da irrigação por gotejamento no crescimento e na produtividade da figueira 'Roxo de Valinhos' (*Ficus carica* L.), aos 3 anos de idade, bem como determinar os coeficientes de cultivo (Kc) e seu consumo hídrico (ETc) nas condições edafoclimáticas da Baixada Fluminense, no Estado do Rio de Janeiro. O estudo foi realizado na área experimental do Sistema Integrado de Produção Agroecológica - SIPA (Seropédica - RJ), no período de julho/2011 a maio/2012. A área experimental foi dividida em dois blocos, denominados B1 (textura francoargiloarenosa) e B2 (textura francoarenosa). Em cada bloco, foram avaliados turnos de rega (TR) de 2 (T1) e 4 dias (T2), além do tratamento sem irrigação (T3). O manejo da irrigação e a determinação do consumo hídrico foram realizados por meio do balanço de água no solo, utilizando-se da técnica da TDR. O crescimento das plantas não foi afetado significativamente pelo TR, diferindo-se apenas no número de entrenós emitidos. Para as duas texturas de solo, o Kc médio foi de 0,60, com diferença estatística ($p \leq 0{,}05$) apenas para TR. A produtividade média estimada não apresentou diferença significativa entre as duas classes texturais avaliadas, variando de 6.612 kg ha^{-1} (T3) a 8.554 kg ha^{-1} (T1). Este estudo sinaliza a importância do turno de rega, sob diferentes características físicas do solo, no manejo da irrigação da figueira.

PALAVRAS-CHAVE: Coeficiente de cultivo, *Ficus carica* L., TDR, turno de rega, balanço hídrico.

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INTRODUCTION

The fig tree (*Ficus carica* L.), belonging to the family Moraceae, is one of the oldest cultivated plants in the world. Brazil is currently the 10^{th} largest world producer, reaching an annual production of 27,727 tons (FAO, 2012). According to IBRAF (2009), the Brazilian fig production represented 0.06% of all fruits produced in the country in 2009, with a cultivated area of 3,072 hectares. Also, it was third in Brazilian exports of temperate fruits, with 1.45 thousand tons, only after apples (90.48 thousand tons) and grapes (60.81 thousand tons).

Considered a rustic plant (RODRIGUES et al., 2012), is one of the fruit species of great economic significance and global expansion, presenting good adaptation to different climates and soils. The Mediterranean arid regions hold the largest cultivation areas in the world; Turkey is responsible for 27% of the world production (ÇALIŞKAN & POLAT, 2008). In Brazil, fig trees are cultivated in different regions, reaching yields of 15 t ha^{-1} around Santa Maria county, Rio Grande do Sul State (FRONZA et al., 2010), 15.8 t ha^{-1} in Quatro Pontes, Paraná State (DALASTRA et al., 2009), 16.6 t ha^{-1} in Botucatu, São Paulo State (LEONEL & TECHIO, 2010), and 11.9 t ha^{-1} in Campos dos Goytacazes, Rio de Janeiro State (CAETANO et al., 2005). In semiarid regions, the irrigated cultivation of fig trees is reccommended, since fruiting is staggered in different plots, during the whole year, enabling fruit production during the intercrop period, when dormancy by cold is replaced by dormancy by drought.

According to PEREIRA (1981), fig trees adapt to different soils, but the most appropriate are those of clayey-sandy texture, rich in organic matter and pH ranging from 6.0 to 6.8. In poorly drained soils, there might be root rots while in those excessively dry, plants remain under a resting state, developing few leaves and not producing fruits.

Despite de irrigation importance for the achievement of greater yield and fruits of better quality (MELGAREJO et al., 2007), there are few studies in the literature on the irrigation management of fig trees. Furthermore, specific studies on the quantification of this species' water requirement are even rarer all over the world. HERNANDEZ et al. (1994) studied the effect of different irrigation levels on fig trees in the region of Ilha Solteira, São Paulo State, and concluded that the applied levels promoted positive effects on the yield of ripe fruits, total yield, branch length, and length and diameter of ripe fruits, recommending the application of 75% of Class A pan evaporation. LEONEL & TECCHIO (2010), when evaluating the pruning effect, either in the presence or absence of irrigation, from July to October, concluded that the irrigation practice promoted higher harvest numbers and expansion of the production cycle.

The Kc value of 0.47, found by OLITTA et al. (1979) in an experiment conducted in Piracicaba, São Paulo State, is used in almost all studies published in Brazil. Although there are researches on the water requirement for some producing regions (KONG et al., 2013), this kind of work is not usually found in the literature, especially for Mediterranean and other countries with water deficit problems.

Considering the above, the objective of this work was to evaluate the effect of the drip irrigation management on growth and yield of the 'Roxo de Valinhos' fig tree (*Ficus carica* L.), at three years old, as well as to determine crop coefficients (Kc) and its water requirement (ETc) under Baixada Fluminense climate and soil conditions, in Rio de Janeiro State, Brazil.

MATERIAL AND METHODS

The study was carried out from July 2011 to May 2012, at SIPA (Sistema Integrado de Produção Agroecológica), located in Seropédica, Rio de Janeiro State, Brazil (22º 46' S and 43º 41' W, approximately 33 m of altitude), which is used for ecological agriculture practices. The soil in the studied area is classified as Red Yellow Podzolic. According to CARVALHO et al. (2011b), the climate in the region is of Aw type, following Köppen classification, with high temperatures and rain in summer, and dry winter with mild temperatures. Rainfall is concentrated from November to March, with an annual mean of 1,213 mm, and mean annual temperature of 24.5 °C.

The experiment was carried out in an area of 780 m^2, cultivated with fig trees (*Ficus carica* L.), Roxo de Valinhos variety, and spaced 3 x 2 m. Despite the risk of adjective energy inputs into the experimental area, its dimension characterizes the small rural properties in this and other Brazilian regions, which present diverse and simultaneous crops. Furthermore, under tropical conditions, solar radiation is the main evapotranspiration component and only a small part is due to aerodynamic ones.

Seedling planting was performed in December 2008 with three posterior pruning periods. This study began after the second fruit pruning, which happened on July 6, 2011, and finished on June 5, 2012, with the harvest end and third fruit pruning.

Based on the chemical soil analysis, performed from samples collected in the experimental area at 0-0.2 and 0.2-0.4 m depths, a potassium and phosphorus complementation was not necessary along the experimental period. However, as nitrogen is the most required element, fertilization with castor bean meal was performed, which was divided along the plant cycle. Phytosanitary treatments and weed management were carried out when necessary, always considering the production organic system techniques (ESPÍNDOLA et al., 2006).

By means of physical analysis (Table 1), which were performed from a sampling grid, it was possible to find a variation in the water and physical soil conditions in the experimental area, which presents a small slope on its surface, promoting a decrease in the clay fraction. The experimental area was then divided in two blocks, named B1 and B2. Soil samples were collected at 0-0.2 and 0.2-0.4 m depths, which is considered the layer of most influence on the crop root system as it is fibrous and, in general, shallow.

TABLE 1. Soil physical characteristics of blocks 1 and 2.

Block/Layer (m)	Sand	Silt	Clay	Textural Class	Bd	θ_{fc}	θ_s
		%			kg dm^{-3}	cm^3 cm^{-3}	
B_1/0.0-0.2	71	8	21	Sandy Clay Loam	1.27	0.227	0.446
B_1/0.2-0.4	70	6	24	Sandy Clay Loam	1.24	0.224	0.427
B_2/0.0-0.2	81	6	13	Loamy Sand	1.32	0.169	0.329
B_2/0.2-0.4	79	6	15	Loamy Sand	1.34	0.175	0.355

θ_{fc} – volumetric soil moisture corresponding to field capacity; θ_s – volumetric soil moisture corresponding to saturation; Bd – bulk density.

The experiment was arranged in an unifactorial scheme, and the experimental design was arranged in a complete randomized block design. Block 1 was characterized as a sandy clay loam soil, and Block 2, as a loamy sand soil. Three treatments were evaluated: two irrigation frequencies (two- and four-day intervals, respectively T1 and T2) and the absence of irrigation (T3). Each block had 24 experimental units, with eight replications per treatment (Figure 1). Each experimental unit (used plant) represented an area of 6 m².

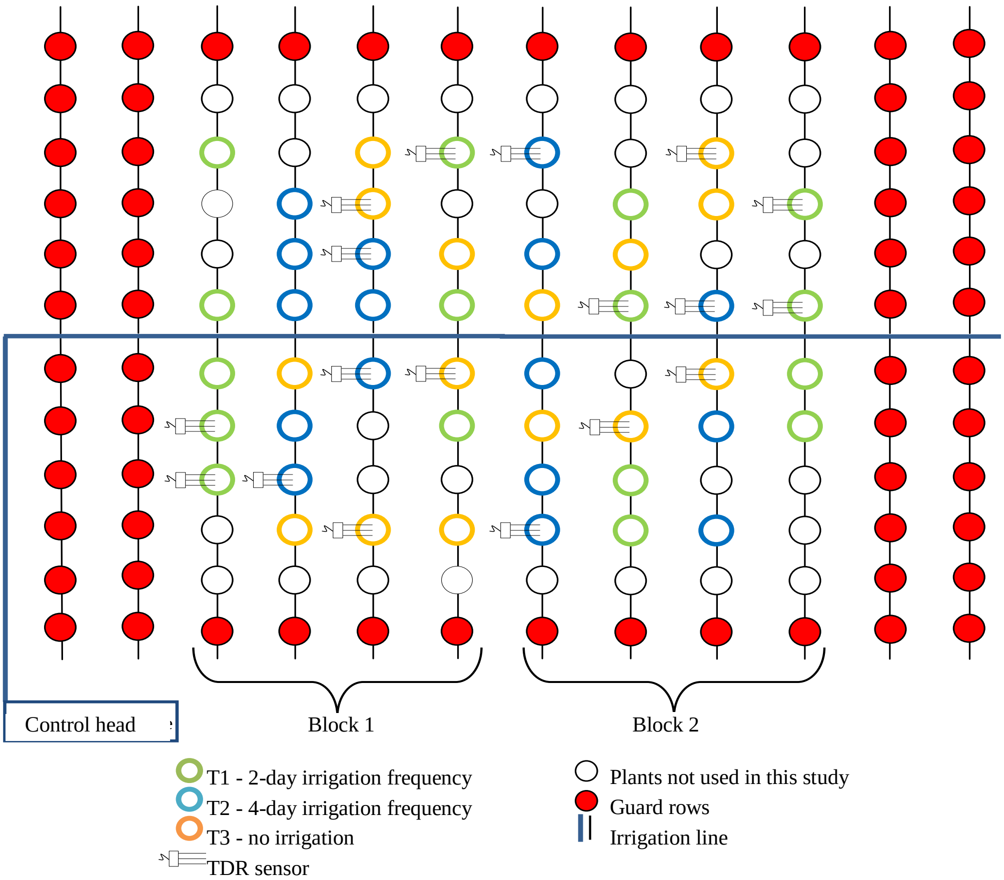


FIGURE 1. Sketch of the experimental area.

The used irrigation system was the drip one, with three drippers per plant and nominal flow of 8 L h^{-1}. After its installation, uniformity tests were performed, resulting in Christiansen uniformity coeffcients (CUC) of 96% and distribution uniformity (DU) of 94%.

Irrigation management began on July 21, 2011, and was carried out according to the soil water balance; moisture was monitored by the TDR technique (Time Domain Reflectometry) (SOUZA & FOLEGATTI, 2011). Sensor calibration was performed based on daily readings of the apparent dielectric constant (ka) and respective determination of soil moisture by the gravimetric model. According to CARVALHO et al. (2013), soil samples were collected in calibration bowls built in representative locations of both textural classes, where sensors with 0.15 m length metal rods were horizontally installed at 0.2 and 0.4 m depth. From the volumetric moisture (θ) and kA data, the following adjustment equations were obtained via simple regression analysis: $\theta_{20} = 0.0099$ ka + 0.1048 and $\theta_{40} = 0.011$ ka + 0.103 (for B1), and $\theta_{20} = 0.0132$ ka + 0.0213 and $\theta_{40} = 0.0108$ ka + 0.0401 (for B2). TDR sensors were installed in three experimental plots of each treatment (Figure 1), allowing soil water status monitoring and appropriate irrigation management of the irrigated treatments (T1 and T2). From soil moisture monitoring with TDR sensors, crop evapotranspiration (ETc) could be estimated according to YIHUN et al. (2013), using the soil water balance (Equation 1).

$$\mathrm{ETc} = \mathrm{I} + ER \pm \Delta\mathrm{SW}\text{, where:} \tag{1}$$

I = Applied irrigation level (mm);
ER = Effective rainfall (mm);
ΔSW = variation of the soil water content (mm).

For the irrigation management practice, EF is considered the level of precipitated water (mm) that, once is infiltrated, is effectively used by the crop. In this study, ER quantification was performed according to readings from an automatic weather station located beside the experimental field and, also, to the TDR readings, having as a reference the soil water retention capacity (CARVALHO et al., 2011a). As the water balance was performed daily, it was possible to evaluate the minimum rainfall fraction able to raise soil moisture up to field capacity at the 0.0-0.4 m depth, always considering rainfall frequency and intensity and, also, the irrigation schedule. The ΔSW component in equation 1 was also obtained by the TDR technique.

The equation of the soil water balance presents other variables, such as capillary rise, runoff, and in and out surface flows, which were considered null because of the area characteristics, like the flat relief, soil physical characteristics, and used irrigation system, apart from soil moisture monitoring (GARCIA & GARCIA et al., 2009).

As the soil water content did not reach values that could promote an expressive water deficit for the fig crop, crop coefficients (kc) were monthly determined for both irrigated treatments via the ratio between ETc and ETo (reference evapotranspiration). ETo was determined according to the Penman-Monteith-FAO method (ALLEN et al., 1998) from the information collected at a weather station located beside the experimental area.

For each irrigation, the applied level was determined according to the TDR readings considering the water requirement for replacement of the soil water up to field capacity (θ_{fc}) (Table 1) at the root system layer (YIHUN et al., 2013). Therefore, irrigation water percolated below the root system was not observed. Due to rainfall occurrence, the irrigation schedule was continually evaluated, always maintaining the characterization of the treatments (intervals among irrigation times).

Plant development was evaluated along the whole crop cycle via non-destructive analysis of growth. The evaluated crop characteristics were number of fruits per plant, total estimated yield of unripe fruits for industry, mean branch length, and number of branch internodes. Fruit harvest were performed weekly, from November 2011 to May 2012, during the crop stationary period and up to three weekly harvests during the production peaks.

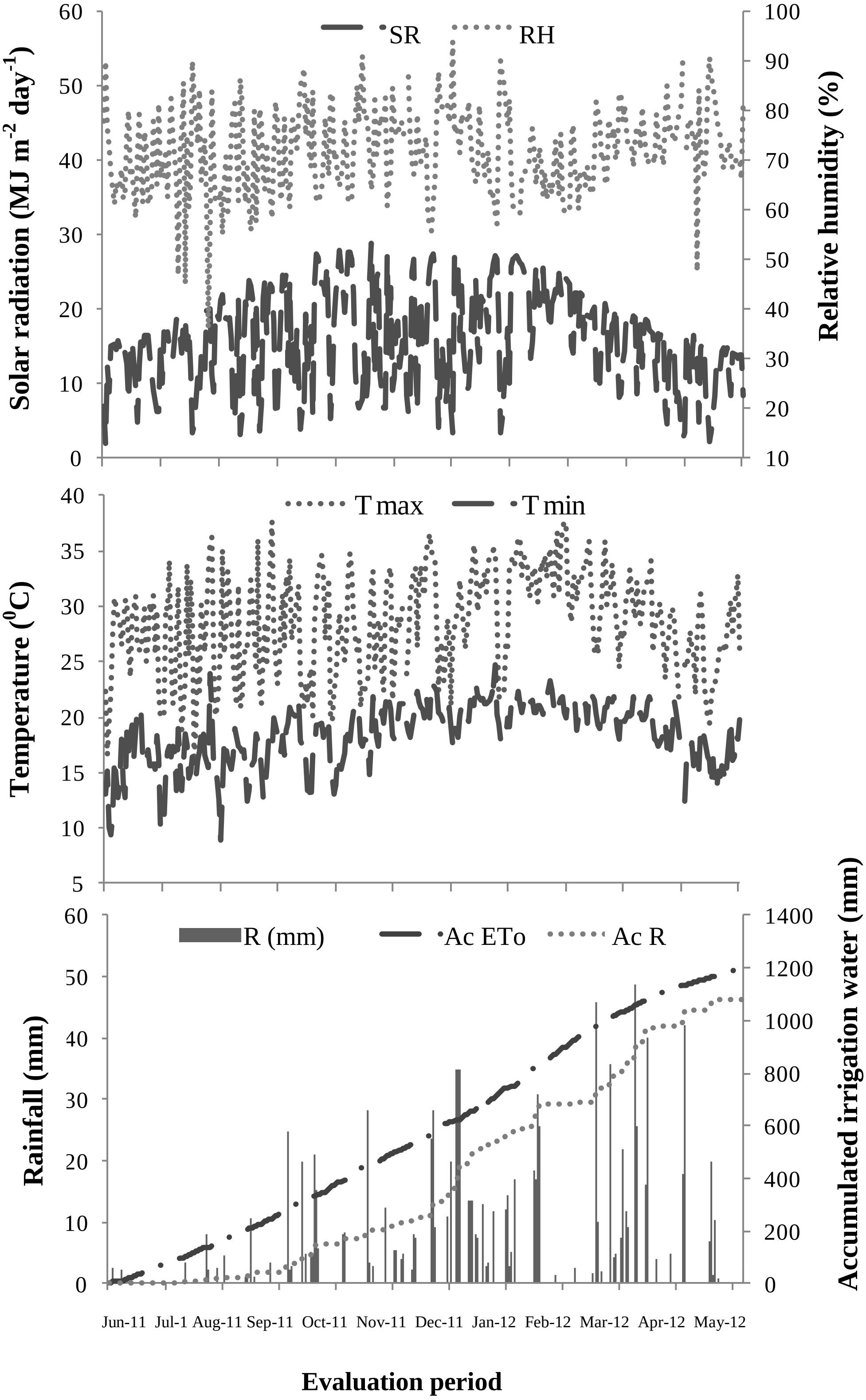
The results obtained after the treatment implementation, as well as monthly applied irrigation levels, were submitted to the variance analysis ($p \leq 0.05$) by the F test, and treatments were compared by the Tukey test at 5% significance level (MACHADO & CONCEIÇÃO, 2007).

RESULTS AND DISCUSSION

Values of solar radiation, air relative humidity, and maximum and minimum temperatures, collected during the experimental period, as well as the behavior of rainfall, ETo and accumulated rainfall are presented in Figure 2. Maximum and minimum values of maximum and minimum temperature for the studied period were 37.7 and 16.5 °C, and 24.8 and 8.9 °C, respectively. These temperatures did not cause any negative impact on the crop since it is primarily from a Mediterranean climate, which is characterized as a temperate climate subtype, with temperature variations ranging from -3 and 18 ºC on the coldest month, hot and dry summers, and rainy and cold winters (SOUZA et al., 2009). Average values of maximum, minimum, and mean air relative humidity were 94.3, 37.0, and 76.1%, respectively.

During the experimental period (from July 2011 to May 2012), there was 1,092.5 mm of rainfall, which was concentrated in December-January and March-April. The solar radiation, considered an important evapotranspiration meteorological component, presented maximum and mean values of 28.9 and 17.5 MJ m^{-2} day^{-1}, respectively; ETo totalized 1,194.0 mm.

After analysis of the obtained results, significant differences were not verified because of the variation of the textural classes; therefore, only paired comparisons of the results were performed for all treatments.



SR – Solar Radiation; RH – Air Relative Humidity; Tmax – Maximum Temperature; Tmin – Minimum Temperature; R (mm) – Rainfall; Ac ETo – Accumulated Reference Evapotranspiration; Ac R – Accumulated Rainfall.

FIGURE 2. Meteorological data observed during the evaluation period.

The monthly mean water levels applied for each treatment are presented in Table 2, resulting in 816.4, 574.9, and 269.8 mm for T1, T2, and T3, respectively.

TABLE 2. Monthly mean water levels per treatment during the evaluation period.

Month	R (mm)	ETo (mm)	Monthly mean water level per treatment (mm)		
			T1	T2	T3
Jul/11	12.6	67.3	26.4 a	19.6 a	10.2 a
Aug/11	20.8	90.7	114.3 a	43.6 b	18.8 c
Sep/11	17.9	103.1	117.5 a	72.8 b	10.1 c
Oct/11	107.8	116.2	95.0 a	70.5 b	31.1 c
Nov/11	74.5	116.0	67.3 a	53.8 a	30.8 b
Dec/11	122.1	119.1	76.9 a	59.2 b	35.3 c
Jan/12	236.0	130.9	57.8 a	52.7 a	30.6 b
Feb/12	93.7	158.5	88.3 a	63.0 b	15.2 c
Mar/12	157.5	129.6	82.2 a	59.9 b	37.4 c
Apr/12	207.6	93.1	50.8 a	44.1 a	37.2 a
May/12	42.2	69.5	39.9 a	35.7 a	13.1 b
Total	1.092.5	1.194.0	816.4 a	574.9 b	269.8 c

Means followed by the same letter in the line do not differ from each other by the F test at 5% probability level.

Along the evaluation period, the mean water level applied (irrigation + effective rainfall) in the 2-day irrigation interval treatment (T1) was statistically similar or superior to that applied in T2; the major differences were observed in August and September 2011 (70.7 and 44.7 mm, respectively), when the lowest rainfall was verified. In this period, water content available in the soil, for T1, was higher when compared with T2, what promoted a more intense evapotranspiration process (DALMAGO et al., 2010). Along all this period, mean values of volumetric moisture determined by TDR before each irrigation were 0.186 and 0.178 cm^3 cm^{-3} for T1 and T2, respectively.

The difference between the highest and lowest total applied water levels was of 546.6 mm, i.e., T3 (treatment without irrigation) received a mean of 33.0 and 46.9% from the total applied water for T1 and T2, respectively.

The fig tree crop coefficientes (Kc) obtained along the crop cycle are shown in Figure 3 for both irrigated treatments. The highest Kc values corresponded to the first cultivation months, when the lowest rainfall was also observed for the site. In general, crop coefficients along the second productive cycle of the fig trees presented decreasing values, with only minor rises along the cycle.

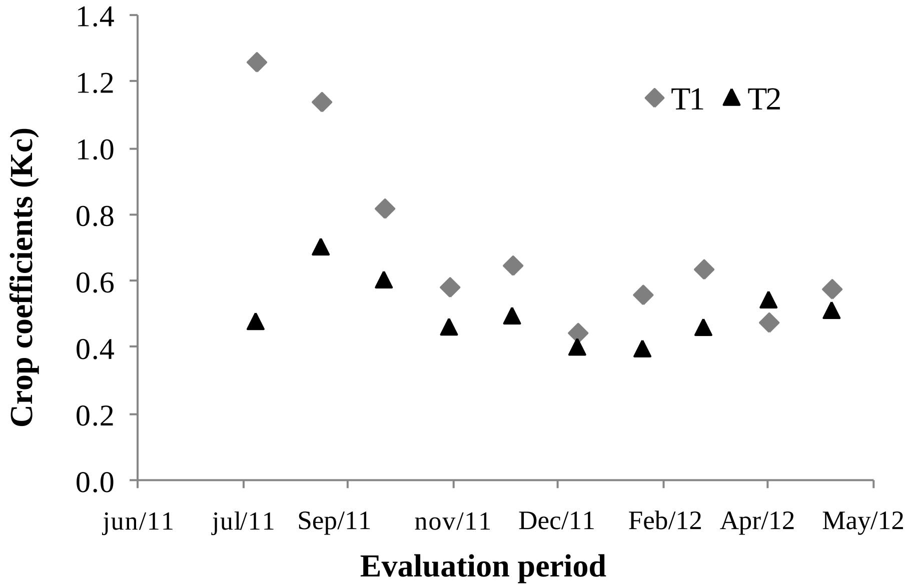


FIGURE 3. Monthly crop coefficients (Kc) of the irrigated treatments.

It is observed that, for almost every month, T1 presented superior Kc values in comparison with T2 due to higher evapotranspiration potential, promoted by higher soil water content.

At the end of the evaluation period, Kc values for all treatments were close to 0.5, when another fruit pruning was performed, initiating another fig production cycle. High Kc values, as well as those irrigation levels applied in the first evaluation months, occurred because of the accumulated water deficit in the experimental area, which was promoted by the previous cultivation in the area, performed without irrigation. ALLEN et al. (1998) comment that, in cases of frequent irrigation or high daily rainfall frequency, Kc values may significantly increase, approaching the range of 1.0-1.2 for all crops.

The behavior of Kc values along the cycle may be explained by the relation among the crop evapotranspiration components (soil evaporation and plant transpiration) associated with self-shading. After pruning, the soil surface around the plant remains exposed, favoring an increase in soil evaporation while transpiration is null or very low. With branch growth and plant self-shading, the evaporation component reduces, but such reduction is compensated by higher plant transpiration. ALVES JÚNIOR et al. (2007) determined Tahiti lime Kc using two weighting lysimeters: one was used to determine the soil evaporation coefficient (Ke); other, to determine the basal crop or transpiration coefficient (Kcb). The authors found a high evaporation value from the soil to young plants because the tree canopy cover was not enough to shade the wet area. Furthermore, due to the fig tree deciduous habit, with the natural fall of the oldest leaves and eventual leaf abscission because of rust and anthracnose attacks, transpiration is reduced; leaves remain then at the tops of the branches, contributing to the decrease of the direct evaporation from the soil.

Mean values of crop coefficients for the irrigated treatments, as well as mean fruit number and yield for each treatment, are presented in Table 3. For the irrigated management of fig tree crops with 2-day intervals, a Kc of 0.71 may be preferably used, but when there is irrigation with 4-day intervals, a Kc of 0.51 must be considered.

OLITTA et al. (1979) evaluated the K factor effect of 0.4, 0.8, and 1.2 water levels from Class A pan, which is the product between Class A pan (Kp) and crop (Kc) coefficients, with a dripping irrigation frequency of one to three times per week for fig trees. The authors found a mean Kc value of 0.47 and concluded that both irrigation intervals did not present a significant difference in the fig production, recommending the K evaporation factor of the Class A pan between 0.4 and 0.8 for any evaluated irrigation frequencies.

TABLE 3. Mean fruit number, mean yield, and crop coefficients of the fig tree for each evaluated treatment.

Treatments	Kc	Yield (kg ha^{-1})	Fruit number
T1	0.71 a	8,554 a	223 a
T2	0.51 b	7,430 ab	194 ab
T3	---	6,612 b	173 b

Means followed by the same letter in the column do not differ from each other by the F test at 5% probability level.

By the end of the evaluation period, a mean of 197 fruits per plant were harvested from all experimental area. The best results were obtained for the 2-day irrigation interval treatment, with 223 fruits that attended the industry commercial standards, representing the production of 5.13 kg per plant and estimated yield of 8,554 kg ha^{-1} (Table 3). This result is similar to the Brazilian national mean of 8,620 kg ha^{-1} (IBGE, 2013), but inferior to those obtained by LEONEL & TECCHIO (2010) and DALASTRA et al. (2009) in Botucatu, São Paulo State, and Quatro Pontes, Paraná State, respectively. It is worth highlighting that both states are traditional fruit producers in Brazil and that São Paulo is the largest fig producer and the only exporter state in the country.

CAETANO et al. (2005), when cultivating a crop with 27 productive branches in northern Rio de Janeiro State, obtained 11,900 kg ha^{-1} yield from six-year-old fig trees.

Irrigation in fig tree crops (mean of both irrigated treatments) promoted a 27% increase in fruit total yield of irrigated plants with 2-day intervals when compared with non-irrigated ones. In all experimental area, the 2-day irrigation intervals in the clayey soil promoted a 47% increase when compared with the non-irrigated sandy clay loam soil. HERNANDEZ et al. (1994) verified that, from the application of 1,461 mm (50% EPan), there were increases of 1,224 and 468% in ripe fruit production and total yield, respectively, what was not found in non-irrigated treatments.

Regarding the analysis of crop growth, plants presented a significant difference for number of produced internodes according to the increase of irrigation frequency, what did not happen for branch length (Table 4).

TABLE 4. Mean branch length (cm) and number of internodes (cm) of the fig trees.

Treatments	Branch length	Number of internodes
T1	88.62^{ns}	45.16 a
T2	90.82^{ns}	43.95 ab
T3	75.01^{ns}	39.93 b

Means followed by the same letter in the column do not differ from each other by the F teste at 5% probability level. ^{ns} non-significant

As it may be observed in Table 4, there were no statistical differences among the evaluated treatments. The number of internodes, however, showed a significant increase according to more frequent irrigations, presenting the maximum value up to 50 internodes per branch by the end of plant development. For branch length, maximum values up to 112 cm were obtained. LEONEL & TECCHIO (2010) found mean branch lengths between 96 and 144 cm in three-year-old fig trees. These authors report that, with the aid of irrigation in the 2004/2005 agricultural year, there were growths of 8.3 in length and 10.2% in mean diameter of the fig tree primary branches, and 18.2% and 19.2% in the secondary branches, in comparison with non-irrigated treatmens. In the following year (2005/2006), the irrigated treatments had lower increments when compared with the previous cycle as, before the beginning of the experiment, plants were cultivated without irrigation. SILVA et al. (2011) found 128 cm length for the irrigated treatment, with mulch application after 275 days of the treatment beginning, what was 42% superior to the non-irrigated treatment with no mulching.

CONCLUSION

The fig tree water requirement was influenced by the irrigation frequency, presenting, for the second production cycle, mean crop coefficients of 0.71 and 0.51 for 2- and 4-day irrigation intervals, respectively. Irrigation management via soil water balance promoted satisfactory results of fig tree development, growth and yield under Baixada Fluminense conditions, resulting in similar yield to the Brazilian national mean for the 2-day irrigation interval treatment.

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