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IRRIGATION STRATEGIES WITH WATER DEFICIT IN 'TOMMY ATKINS' MANGO TREE

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ABSTRACT: With the limited availability of water in semi-arid regions, it is necessary that irrigation is accurate and there is high water use efficiency.This study aimed to evaluate the regulated deficit irrigation (RDI) and partial rootzone drying (PRD) in yield, water use efficiency and gas exchange of 'Tommy Atkins' mango tree in semi-arid conditions. The experimental design was a randomized block with seven treatments for RDI under micro sprinkler and five treatments for the PRD under drip. Treatments were applied in phases PI - early blooming to early fruit expansion, PII - early expansion to early physiologic ripening and in phase III - physiologic ripening of fruits, with application of the RDI of 100, 75 and 50 % of ETc in different combinations of phases and application of PRD 100, 80, 60 and 40 % of ETc in three phases with the partial rootzone druing at 15 days. Photosynthesis, carboxylation efficiency and quantum efficiency of photosynthesis are lower in PRD 40% ETc at 8 a.m. compared to full irrigation and PRD 80 % of ETc. Phases of expansion and fruit ripening are more appropriate for application of RDI with 50 % and 75% of ETc without loss to the crop yield of 'Tommy Atkins' mango tree and greater water use efficiency. The strategy of partial rootzone drying, PRD, every 15 days with 40 % of ETc, provides greater WUE.

KEYWORDS: *Mangifera*, water deficit, water use efficiency.

INTRODUCTION

The semi-arid region of the Northeast, especially Bahia constitutes an agricultural region of high importance to national fruit production. Its climate, coupled with the management of irrigation favor the good development of crops, especially mango tree.

Semi-arid region in Bahia has improved the application of irrigation management practices to raise productivity, fruit quality and water efficiency use in the region since the limiting factors in fruit production is the scarcity and/or irregularity of rainfall, so the limited availability of water, is essential for accuracy high efficiency of water use, which implies irrigation strategies with deficit in order not to compromise the production. In this regard, the irrigation practices designated as Regulated Deficit Irrigation (RDI) and Partial Rootzone Drying (PRD) or irrigation laterally alternate highlights from the reduction techniques of real depth applied (BASSOI et al., 2011; ROMERO-CONDE et al., 2014; SAMPAIO et al., 2014; GHRAB et al., 2014)

The RDI is an irrigation management that involves the application of irrigation deficits in plant development stages whose growth and fruit quality have low sensitivity to water stress and that do not compromise their productivity potential in order to increase their water use efficiency. On the other hand, the irrigation management based on PRD, also known in Brazil as irrigation with partially drying in the root area (SAMPAIO et al., 2010), consists in switching the side of the plant to be irrigated for 10 to 14 days, between phonological stages of fruit set and harvest. To ensure crop production, irrigation should be carried out before the water availability in the soil was reduced to levels that alter the metabolism of the plant, leading to productivity reduction (OLIVEIRA et al., 2011).

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The use theory of these strategies is based in the sense that the water deficit in the soil leads to the production of abscisic acid hormone (ABA) by the roots that translocate through vascular axis, concentrating on the shoot, promoting the partial closing of the stomata, the vegetative growth control and thus reduce water loss to the atmosphere. McCARTHY et al. (2002) points out that the PRD based on biochemical responses of plants to achieve a balance between vegetative and reproductive development through water stress, as a result, there is significant improvement in production per unit of water of irrigation applied. The PRD induced a greater stomatal closure in papaya compared with RDI, for the same water tension in the soil due to the influence of non-irrigated part of the root zone, where water stress induces increased production of abscisic acid (LIMA et al. 2015).

The use of irrigation management with regulated deficit and alternating sideways phases of flowering and fruiting in mango trees in Bahia semi-arid conditions still lacks information to obtain scientific support and generate concrete information that can be extrapolated to fruit growers and is compatible with the current relationship " society- nature".

The use of different strategies and irrigation systems will cause changes in soil water conditions, which combined with the climate can bring reflections on the water status of the plants, with variations on leaf temperature and gas exchange that directly influence the growth, development and cultures production.

In order to contribute to the knowledge on mango irrigation deficit this study aimed to evaluate the effect of irrigation management by the regulated deficit irrigation (RDI) and by partial root- zone drying (PRD) on productivity, water use efficiency and gases exchange on 'Tommy Atkins' mango tree in Semi-arid conditions in Bahia.

MATERIAL AND METHODS

The study was developed in a *Mangifera indica* L. 'Tommy Atkins', 16 years old, located in the Irrigated Perimeter of Ceraíma, Municipality of Guanambi, Bahia Southwest region. The soil of the experimental area was classified as typical Eutorphic Fluvic Neosol. According to Köppen, the climate of the region where the study was conducted is Aw: hot and dry semi-arid, temperature and annual average precipitation of 25.6° C and 680 mm, respectively, and the concentrated rainy season from November to March. The main climatic variables are directly related to water demand and changes in physiological mechanism of culture, occurred during trial period. Those are set out on Figure 1.

Two experiments, one considering water management by the PRD method and another considering the RDI method were installed in a commercial area of the Irrigated Perimeter of Ceraíma in January 2013. The site presents 530 m altitude, and geographical coordinates of 14°17'03" South latitude and 42° 43'57" West longitude. The water used in the irrigation of electrical conductivity of 1.0 dS m^{-1} was obtained from a tubular well that has been applied to the experimental units differentially by a drip type irrigation system with nine dripper of unit flow 8 L h^{-1} and micro sprinklers (flow of 100 L h^{-1}) at a pressure of 200 kPa, in the experiment with the use of the PRD and with the use of RDI, respectively.

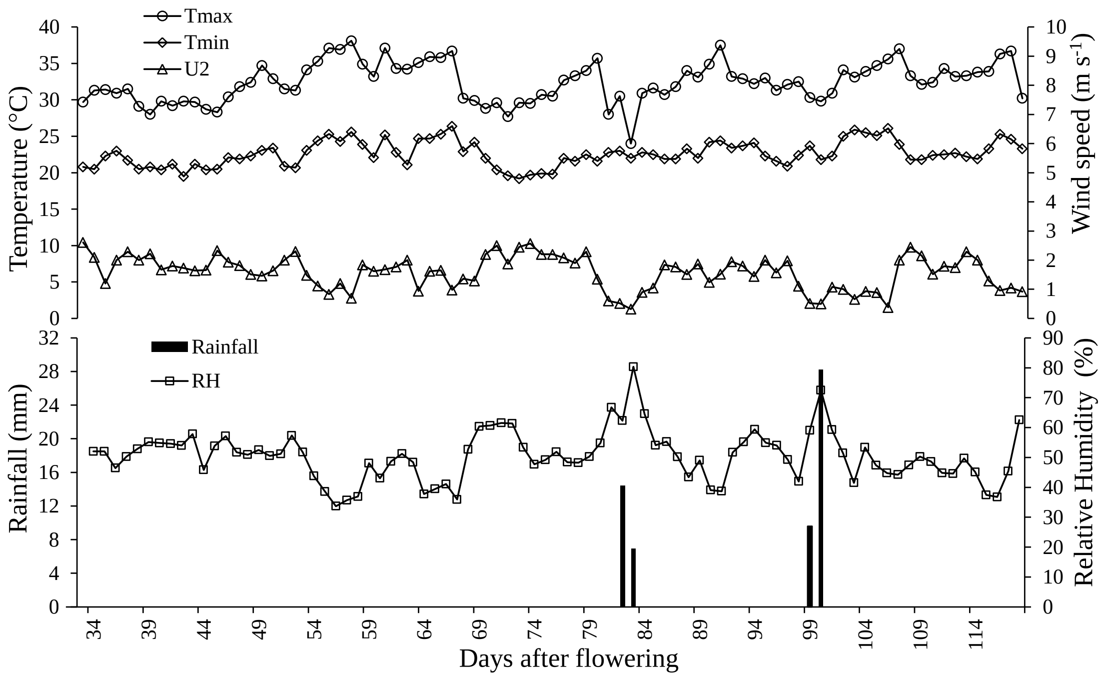

FIGURE 1. Maximum temperature (Tmax), minimum temperature (Tmin), average relative humidity (RH) of the air, wind average speed (U2) and rainfall during the evaluation period, 09/02/2013 to 12/25/2013. Guanambi, BA.

During the production cycle were considered the mango production techniques employed in the irrigated perimeter. The plants after harvesting have been through, pruning, top and central opening trimming and fertilized with 350 g of MAP (monoammonium phosphate; $NH_4H_2PO_4$, 48% of P_2O_5, 10% of N); 250 g of potassium chloride (KCl, 58% of K_2O); 250 g of urea (CO $(NH_2)_2$, 44% of N); 50 g of FTE / plant; 13.5 kg of manure. It was applied at flowering 200 g of calcium nitrate (Ca $(NO_3)_2$, 19% of Ca, 14% of N) per plant in flowering phase and potassium nitrate (KNO_3; 44% of K_2O, 13% of N) during the fruiting phase, there was also foliar application of fertilizers containing Ca and B (375 ml / 100 L H_2O) in the flowering phase. Fertilization was defined from soil analyzes and nutrient extraction estimated based on the production obtained in the previous year.

The analyzes to obtain the physical characteristics of the soil were determined according to EMBRAPA (2011), in IF Baiano Soils Laboratory - *Campus* Guanambi (Table 1).

TABLE 1. Physical and hydric attributes of the soil on the experimental area. Guanambi, BA, 2013.

Parameter	Depth (m)			
	0.00 – 0.25	0.25 – 0.50	0.50 – 0.75	0.75 – 1.00
Sand (g kg^{-1})	600	770	800	760
Silt (g kg^{-1})	240	150	120	160
Clay (g kg^{-1})	160	80	80	80
Water content at - 10 kPa (kg kg^{-1})	0.23	0.16	0.14	0.16
Water content at - 1500 kPa (kg kg^{-1})	0.12	0.07	0.06	0.07

After performing the pruning, irrigation management was conducted daily until the time the plant issued the second vegetative shoot. The stoppage on mango tree growth was performed by applying growth regulator Paclobutrazol (PBZ) at a dose of 1 g of active ingredient per linear meter of canopy diameter (MOUCO & ALBUQUERQUE, 2005). Irrigation remained total (100% of crop evapotranspiration, ETc) for 15 days to ensure product absorption by the plant. Then, irrigation was stopped and when plants showed symptoms of epinasty of the terminal branches, it was conducted three applications of calcium nitrate 3%, at seven days intervals with the purpose of breaking the bud dormancy. These applications were initiated thirty days after the application of PBZ to induce a uniform flowering.

Irrigation treatments with regulated deficit irrigation (RDI) and an partial rootzone drying (PRD) were applied from flowering to ripening of fruits in the three stages of development: the beginning of flowering until the fructification, which occurs around 65 days after the beginning of flowering (Phase I); during fruit development that happens until approximately 95 days after the beginning of flowering (Phase II); and the end of the growth and physiological maturity of the fruit, approximately 120 days after the beginning of flowering (Phase III).

The experimental design was randomized blocks with seven treatments for water management experiment with RDI and five treatments for the experiment with PRD (Table 2). In the PRD the alternation of irrigated side was realized every 15 days from flowering to harvest. In both cases were six replicates and a useful plant per experimental plot and the irrigation water depth was reduced from 100% of the daily crop evapotranspiration.

TABLE 2. Treatments used in the experiment with RDI and PRD at different phases of fruit development of 'Tommy Atkins' mango trees.

Phases of fruit Development	Treatments (% da ETc)						
	IP	RDI50F1	RDI50F2	RDI50F3	RDI75F1	RDI75F2	RDI75F3
Fructification	100	50	100	100	75	100	100
Expansion	100	100	50	100	100	75	100
Maturation	100	100	100	50	100	100	75
	IP	PRD100	PRD80	PRD60	PRD40		
Fructification	100	100	80	60	40		
Expansion	100	100	80	60	40		
Maturation	100	100	80	60	40		

Irrigation was based on crop evapotranspiration (ETc) obtained based on the reference evapotranspiration (ETo), the crop coefficient (Kc) and the location coefficient (KI), calculated as the ratio between the shaded area and area of the plant, obtaining unitary value. Days with precipitation occurrence in the experimental area were subtracted from the crop evapotranspiration to obtain the irrigation time.

The reference evapotranspiration was determined indirectly by the Penman-Monteith method, FAO standard, based on data from the weather station DAVIS Vantage Pro2, installed near the experimental area and the Kc value used to calculate the crop evapotranspiration during the evaluation phases were from 0.42 to 0.87, as used by SANTOS et al. (2014b, 2015). This method considers the number of days after flowering for determining the crop coefficient.

The management of irrigation of the orchard during the experiment, the daily irrigation time was calculated by [eq. (1)], according to SANTOS et al. (2014b, 2015), considering the application efficiency of 0.90.

$$Ti = \frac{ETc \times Rp \times Sr \times Sp \times Kl}{n \times q \times Ae} \quad (1)$$

where,

Ti is the time of irrigation hours;

Rp is the water replacement (decimal);

Sr is the spacing between rows of plants, m;

Sp is the spacing between plants in the row, m;

Kl is the location coefficient, dimensionless, as shown above;

n is the number of emitters (dripper or micro sprinkler) per plant;

q is the flow of the emitters, L h^{-1}, and

Ae is the application efficiency, decimal.

The accumulated irrigation water depth were 345.73; 276.58; 207.44 and 138.29 mm in the treatments IP and PRD100; PRD80; PRD60 and PRD40 respectively in the PRD management and 428.09; 325.06; 370.74; 374.42; 376.58; 399.41; 401.25 mm in the IP; RDI50F1; RDI50F2; RDI50F3; RDI75F1; RDI75F2; RDI75F3 respectively in the RDI management during the experimental period. Treatments were applied at 34 days after flowering and finished at 118 days of full blooms.

After harvest, the fruits were selected for treatment, counted and weighed. The total yield and the numberfor each treatment were compared. The water use efficiency was obtained for all treatments, considering the relationship between productivity and gross depth applied.

The physiological variables were measured with support of the gas analyzer infrared (IRGA) model Lcpro+®Portable Photosynthesis System (ADC Bio Scientific Limited, UK) with temperature and irradiance environment and air flow of 200 ml min^{-1}. They measured the incidence of radiation on the sheet (*Qleaf)* expressed in μmol m^{-2} s^{-1} of photons, leaf temperature (*Tl*) in ºC, internal CO_2 concentration (*Ci*) in μmol mol^{-1}, stomatal conductance (*gs*) in mol m^{-2} s^{-1}, transpiration (*E*) in mmol m^{-2} s^{-1} of H_2O, net photosynthesis (*A*) in μmol m^{-2} s^{-1} of CO_2, instantaneous water use efficiency (*A/E*), carboxylation efficiency (*A/Ci*) and quantum efficiency of photosynthesis (*A/Qleaf*). The measurements were performed at 114 and 115 days after flowering at 8 a.m. and 2 p.m..

For physiological characteristics the treatments were arranged in a 7x2 factorial design to RDI and 5x2 for PRD, being 7and 5 treatments of the respective irrigation management and 2 reading times with the IRGA. The data of the number of fruits, yield, water use efficiency and physiological characteristics were subjected to analysis of variance. Means were compared using the Tukey test and grouped by the criteria of Scott-Knott at 5% probability.

RESULTS AND DISCUSSION

Gas exchange in 'Tommy Atkin' mango trees under partial rootzone drying and regulated deficit irrigation

The carbon reference physiological characteristics - *Cref*, leaf temperature - *Tl*, stomatal conductance – *gs*, and instantaneous water use efficiency *A/E* measured at 114 days after flowering in 'Tommy Atkins' mango tree subjected to partial rootzone drying varied with the time reading, independently (Figure 2). The highest *Cref* at 8 a.m. may be associated with higher CO_2 atmospheric concentrations due to the absence of CO_2 fixation at night. In the course of CO_2 fixing process until 2 p.m. possibly caused reduction in atmospheric CO_2 to cause significant differences. The increase of 20.47% in leaf temperature from 8 a.m. to 2 p.m. reduced stomatal conductance and instantaneous water use efficiency, *A/E*. Even without influence of the measurement time, it increased transpiration 19.70% (from 5.96 to 7.13 mmol m^2 s^{-1} of H_2O) regardless of irrigation and reduced photosynthesis to 53.89% (from 12.94 to 5.97 μmol m^2 s^{-1}de CO_2), leading to the decrease in the ratio *A/E* as evidenced by DONATO et al. (2015a, b) that *A/E* decreases with increasing temperature, even with the increased of the irrigation water depth applied to 125%, ETc.

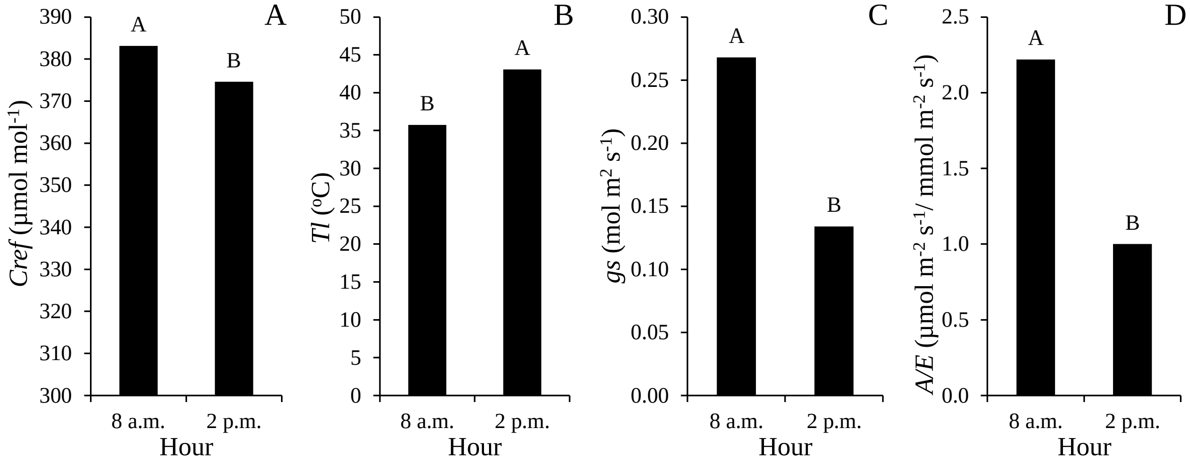

FIGURE 2. Carbon reference - *Cref* (A), leaf temperature - *Tl* (B), stomatal conductance - *gs* (C) and instantaneous water use efficiency - *A/E* (D) in 'Tommy Atkins' mango tree under the PRD times 8 a.m. and 2 p.m.. Guanambi, BA, 2013. Means followed by different letters in the bar differ (P <0.05) by Tukey test.

Photosynthesis, carboxylation efficiency and quantum efficiency of photosynthesis in 'Tommy Atkins' mango tree was influenced by the interaction between time and irrigation (Table 3). With the exception of the PRD irrigation at 40% of ETc, photosynthesis, carboxylation efficiency and quantum photosynthesis effectiveness of 'Tommy Atkins' mango tree were higher at 8 a.m. than at 2 p.m. At 8 a.m. the *A* was lower in PRD 40% compared to the PRD 80%, *A/Ci* and *A/Qleaf* were smaller in the management of the PRD irrigation at 40% of ETc compared to full irrigation and PRD 80% of ETc, while at 2 p.m. *A*, *A/Ci* and *A/Qleaf* were similar in all irrigation management with PRD. It is observed also on Table 3 that photosynthesis is similar at 8 a.m. and 2 p.m., which reflects the influence of water deficit at 40% of ETc on quantum efficiency of photosynthesis and carboxylation efficiency. In this aspect, the intensity of water deficit at 40% of the ET_C is equivalent to the influence of higher ambient temperatures which causes change in temperature and reduction in leaf photosynthesis.

The highest temperature recorded at 2 p.m. in relation to 8 a.m. represents a decline in the conditions for the plants with full irrigation or submitted to lower intensity of water deficit, affects the enzyme system and decreases the photosynthetic rates and efficiencies. However for plants under higher water deficit the stress intensity yet actives defense mechanisms that reduces photosynthesis even in the most favorable hours like the stomatal closure.

TABLE 3. Photosynthesis - *A*, carboxylation efficiency - *A/Ci* and quantum efficiency of photosynthesis - *A/Qleaf* in 'Tommy Atkins' mango tree under different managements of partial rootzone drying and schedules. Guanambi, BA, 2013.

Parameter	Irrigation	Time		CV (%)
		8 a.m.	2 p.m.	
A	IP	14.93ABa	5.71Ab	29.62
	PRD100	12.06ABa	6.79Ab	
	PRD80	15.48Aa	5.19Ab	
	PRD60	14.11ABa	5.00Ab	
	PRD40	8.13Ba	7.14Aa	
A/Ci	IP	0.0596Aa	0.0217Ab	30.18
	PRD100	0.0501ABa	0.0271Ab	
	PRD80	0.0652Aa	0.0204Ab	
	PRD60	0.0591ABa	0.0209Ab	
	PRD40	0.031Ba	0.0294Aa	
A/Qleaf	IP	0.0091Aa	0.0033Ab	31.13
	PRD100	0.007ABa	0.0039Ab	
	PRD80	0.0091Aa	0.0030Ab	
	PRD60	0.0084ABa	0.0030Ab	
	PRD40	0.0046Ba	0.0043Aa	

Means followed by different letters capital letters in the column and lower case in line differ (P <0.05) by Tukey test.

Under CO_2 environmental concentration, the increase in temperature modifies the rubisco kinetic constants and increases the oxygenation rate, preferably carboxylation, increases photorespiration and decreases net photosynthesis, as seen in Figure 3. Values above 30°C, as recorded in this study cause drop in photosynthesis (DONATO et al, 2015 a), as the photosynthetic reactions have a Q_{10} of about two between 12 and 30 ºC (TAIZ & ZEIGER, 2013). As a result of the reduction in photosynthesis by increasing the leaf temperature, there is a negative correlation between *A/Ci*, *A/Qleaf* and *A/E* with *Tl* (Figure 3B, C and D) by enzyme involvement. However, there is positive correlation to associate stomatal conductance with *A/Ci* and with *A/Qleaf* (Figure 3F and G), since higher stomatal conductance is related to higher input of CO_2. This increase in substrate concentration in the rubisco site compensates the negative effect of temperature on photosynthesis, favoring carboxylation reactions as the enzyme has low affinity with CO_2 (TAIZ & ZEIGER, 2013).

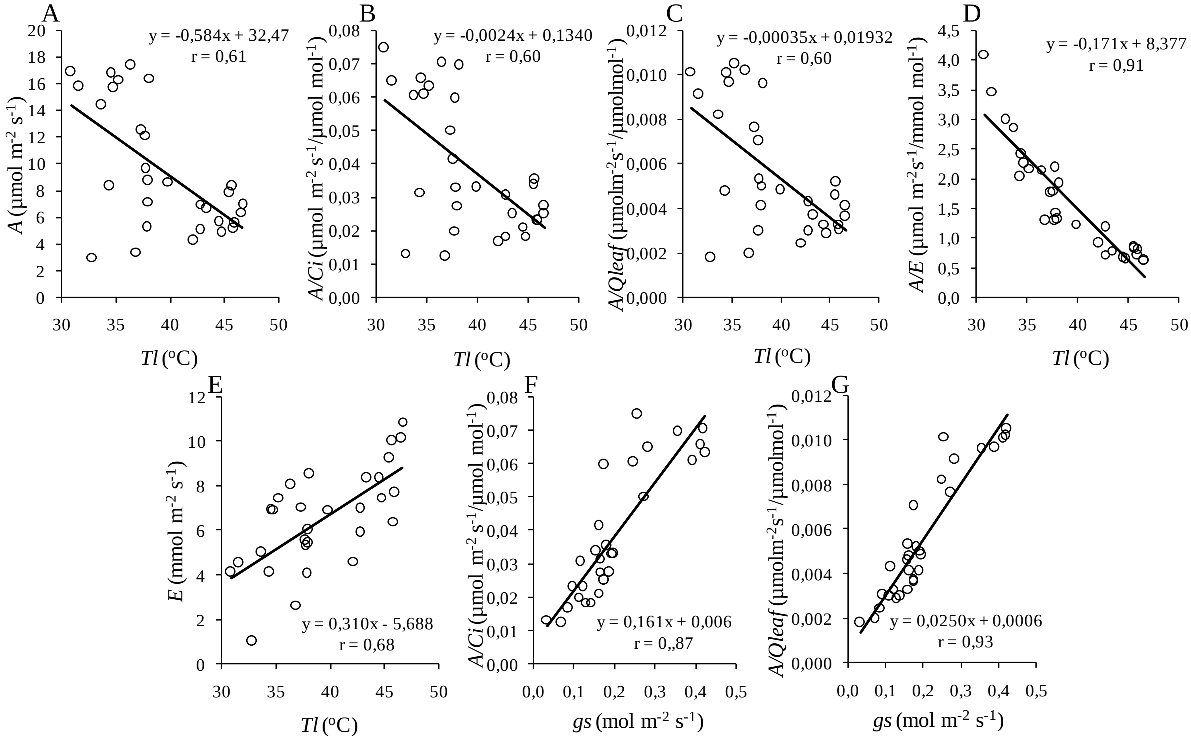

FIGURE 3. Photosynthesis - *A* (A), carboxylation efficiency - *A/Ci* (B); quantum efficiency of photosynthesis - *A/Qleaf* (C), instantaneous water use efficiency - *A/E* (D), transpiration - *E* (E) as a function of leaf temperature (*Tl*), carboxylation efficiency - *A/Ci* (F) and quantum efficiency of photosynthesis - *A/Qleaf* (G) as a function of stomatal conductance (*gs*) in 'Tommy Atkins' mango tree under partial rootzone drying. Guanambi, BA, 2013.

The lower photosynthetic rates, lower carboxylation efficiency - *A/Ci*, lower quantum efficiency of photosynthesis - *A/Qleaf* and lower instantaneous water use efficiency - *A/E* at 2 p.m. (Figure 4), regardless of irrigation strategy used, it can be explained by higher values of *Tl* in some treatments with RDI (Table 4). The increase of leaf temperature possibly caused imbalance between carboxylase and oxygenase activity of the rubisco (DONATO et al., 2015a).

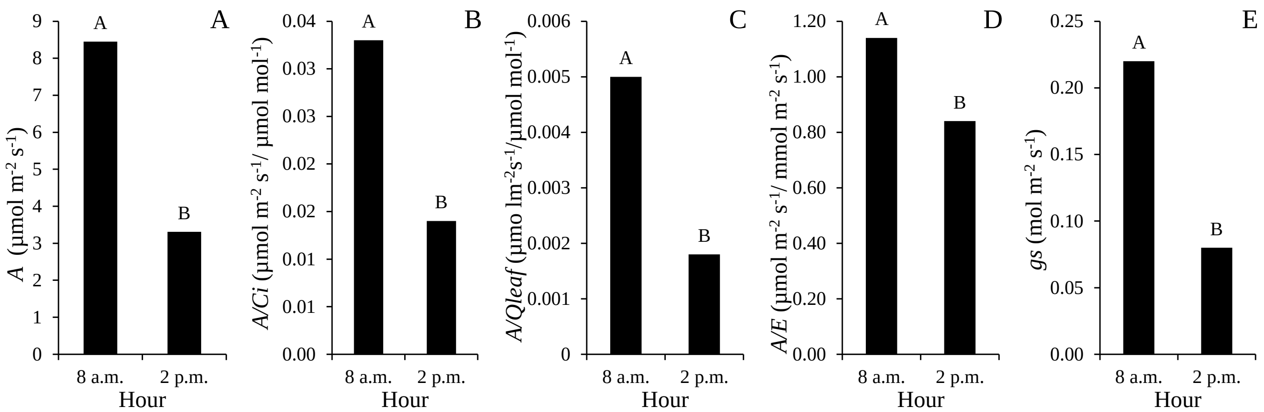

FIGURE 4. Photosynthesis - *A* (A), carboxylation efficiency - *A/Ci* (B), quantum efficiency of photosynthesis - *A/Qleaf* (C), instantaneous water use efficiency - *A/E* (D) and stomatal conductance - *gs* (E) in 'Tommy Atkins' mango tree under RDI at 8 a.m. and 2 p.m.. Guanambi, BA, 2013. Means followed by different letters in the bar differ (P <0.05) by Tukey test.

TABLE 4. Carbon reference - *Cref*, incident photosynthetically active radiation - *Qleaf*, leaf temperature *Tl* and transpiration – *E* in 'Tommy Atkins' mango tree under different RDI and two measurement time. Guanambi, BA, 2013.

Parameter	Time	Irrigation							CV
		IP	RDI50F1	RDI50F2	RDI50F3	RDI75F1	RDI75F2	RDI75F3	
Cref	8 a.m.	376.33Aa	374.55Aa	374.44Aa	373.00Aa	374.11Aa	378.11Aa	376.44Aa	1.32
	2 p.m.	371.33Ca	364.33Cb	367.33Ca	363.67Cb	364.33Cb	386.33Aa	377.00Ba	
Qleaf	08 a.m.	1693.78Ab	1655.78Bb	1696.11Aa	1711.89Aa	1711.00Ab	1728.00Aa	1647.44Bb	1.96
	2 p.m.	1843.00Aa	1804.00Aa	1703.33Ba	1707.33Ba	1879.67Aa	1765.00Ba	1722.67Ba	
Tl	8 a.m.	40.53Aa	41.40Ab	41.34Ab	42.00Ab	41.52Ab	39.733Aa	40.77Aa	3.81
	2 p.m.	42.20Ba	45.80Aa	44.13Ba	46.47Aa	46.50Aa	36.10Db	39.97Ca	
E	8 a.m.	8.27Aa	7.93Aa	6.89Aa	7.58Aa	7.81Aa	7.24Aa	8.10Aa	34.93
	2 p.m.	5.30Ba	10.65Aa	2.60Cb	3.19Cb	6.28Ba	1.41Cb	2.52Cb	

Means followed by different letters, capital on the line, form different groups ($P < 0.05$) by the criterion of Scott-Knott and lower case on column differ ($P < 0.05$) by Tukey test.

Photosynthesis in mango tree under full irrigation and regulated deficit irrigation at 50% of ETc in phase I formed a group and the other managements another one (Figure 5A). As the measurement was carried out in phase III, and RDI50F1 treatment received irrigation deficit at 50% of ETc in phase 1, and then the plants were subjected to 100% of ETc in phases 2 and 3, possibly enabled the maintenance of same photosynthetic rates that the plants under full irrigation. On the other hand, plants subjected to RDI with 50 and 75% of ETc in phase 2 at 100% of ETc in phase 3 did not develop in 20 days, readaptation mechanisms for the full realization of CO_2 fixation, presented lower photosynthetic rates. SANTOS et al. (2013) observed that mango plants subjected to water deficit at 50% ETc had reduced in photosynthesis, which corroborates with the results of this study.

In phase 3, the highest water use efficiency (*A/E*) were for the plants of 'Tommy Atkins' under full irrigation in all three phases, RDI with 75% of ETc in phase 2 and 3 (Figure 5D). The higher *A/E* in plants was subjected to 75% of RDI on ETc in Phase 2 and 3 can be explained by the decay on transpiration values (*E*) (Figure 5B). It is emphasized that even on partial deficit, plants can develop homeostasis maintenance mechanisms such as synthesis of HSPs heat shock proteins common in plants belonging to anacardiaceas family as cashew, mango, mastic (GONDIM et al., 2014), preventing enzymatic damage, and resulting in higher instantaneous efficiency on water use. SANTOS et al. (2013) argue that when the water deficit in the soil is not very pronounced, changes in stomatal conductance follow the same trend of the plants without water deficit and the reduction of 50% on ETc on mango culture does not cause significant reduction on transpiration.

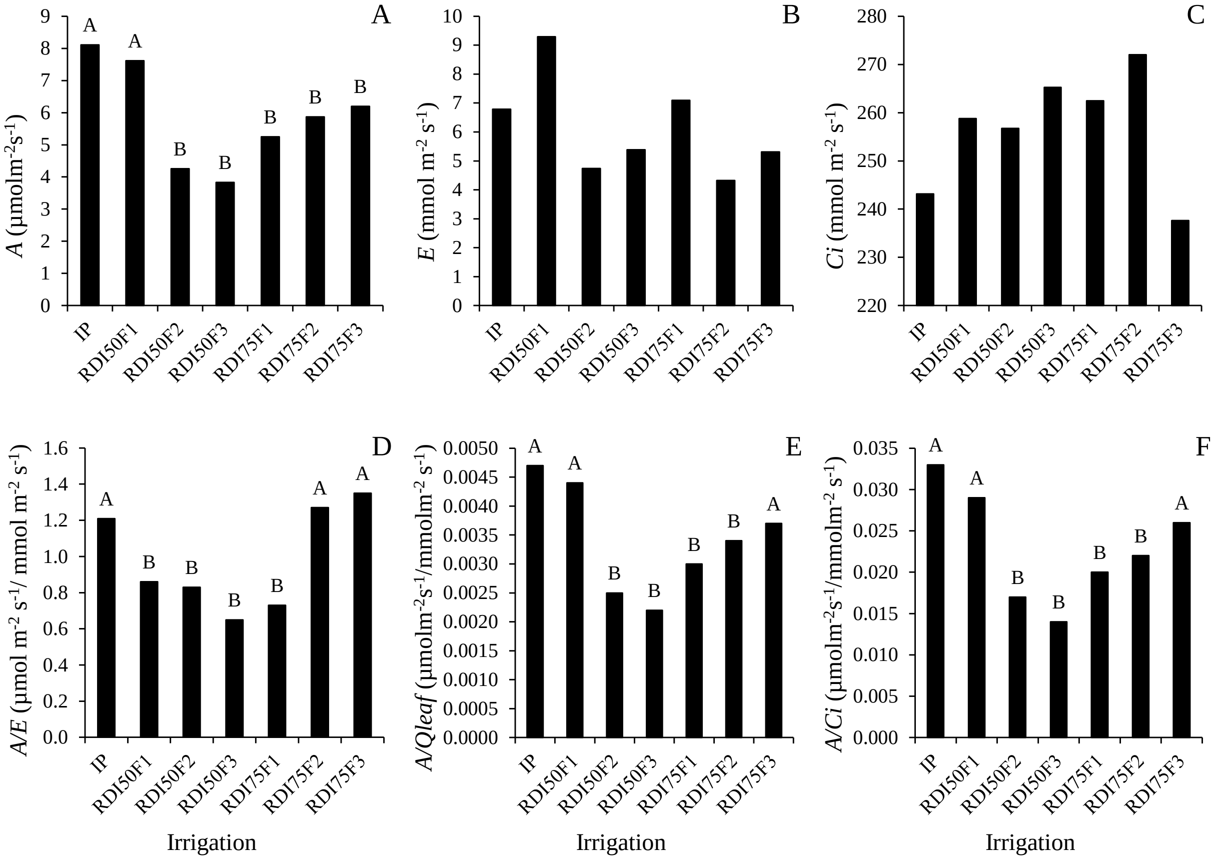

FIGURE 5. Photosynthesis - *A* (A), transpiration - *E* (B), internal CO_2 concentration - *Ci* (C), instantaneous water use efficiency - *A/E* (D), quantum efficiency of photosynthesis - *A/Qleaf* (E) carboxylation efficiency - *A/Ci* (F), in 'Tommy Atkins' mango tree under different irrigations with RDI. Guanambi, BA, 2013. Means followed by different letters in the bar differ (P <0.05) by Tukey test.

The quantum efficiency of photosynthesis (*A/Qleaf*) and carboxylation efficiency (*A/Ci*) in 'Tommy Atkins' mango trees behaved similarly when subjected to regulated deficit irrigation. By the criteria of Scott-Knott, the plants under full irrigation in all three phases, RDI at 50% of ETc on phase 1 and RDI at 75% of ETc on phase 3 with the highest values of *A/Qleaf* and *A/Ci* formed a single group.

Even while expressing higher photosynthetic rate, the higher instantaneous water use efficiency, higher quantum efficiency of photosynthesis and higher carboxylation efficiency in plants subjected to RDI at 50% of ETc in phase 1 with these measurements performed in phase 3 in which plants already had undergone to 100% of ETc on phase 2 and phase 3, it did not result in production increase (Figure 8). This indicates that should not be used RDI in the fruit formation phase (phase 1), even the plants in the next phases develop recovery mechanisms of gas exchange because the production is compromised.

Transpiration (*E*), photosynthesis (*A*), carboxylation efficiency (*A/Ci*) and quantum efficiency of photosynthesis (*A/Qleaf*) positively correlated with the stomatal conductance, while the instantaneous water use efficiency expressed negative correlation with leaf temperature (*Tl*) in 'Tommy Atkins' mango tree under RDI (Figure 6). The *gs* is responsible for the CO_2 input and output flow of water through the stomata; as larger the opening as smaller the stomatal resistance and, consequently, increased transpiration (TAIZ & ZEIGER, 2013).

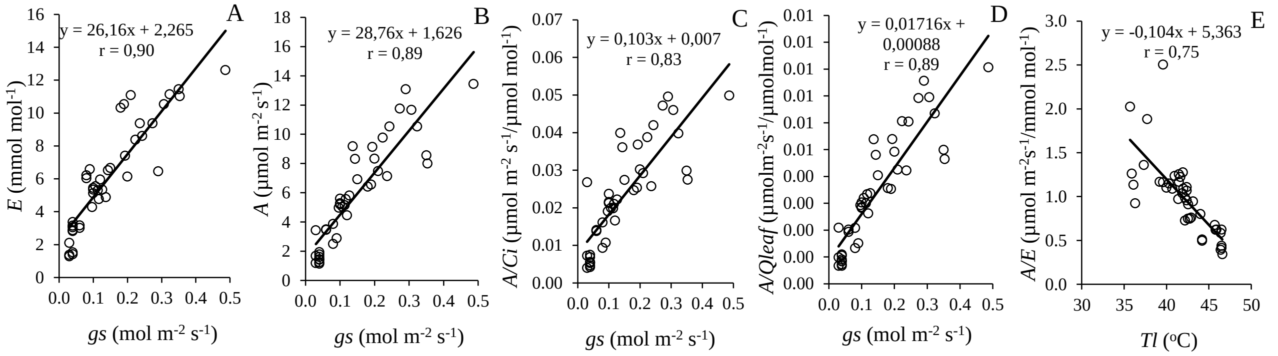

FIGURE 6. Transpiration - *E* (A) Photosynthesis - *A* (B) carboxylation efficiency - *A/Ci* (C) quantum efficiency of photosynthesis - *A/Qleaf* (D) as a function of stomatal conductance and instantaneous water use efficiency - *A/E* (E) as function of leaf temperature (*Tl*) in 'Tommy Atkins' mango tree under regulated deficit irrigation. Guanambi, BA, 2013.

Production and efficiency of water use under partial rootzone drying and regulated deficit irrigation

Despite the non-occurrence of significant differences between treatments, the amount of fruit per hectare was 54.1% and productivity of 34.9% higher for the treatment with partial rootzone drying at 80% of ETc, compared to full irrigation, evaluated in three phases (Figure 7).

The management of the PRD irrigation influences the water use efficiency by 'Tommy Atkins' mango tree (Figure 7). Considering the average irrigation depths the PRD management, there is an increased in water use efficiency of PRD at 40% of ETc in comparison to treatment of full irrigation. It is also observed that plants under the management with the PRD technique with lower water replacements had higher productivity than the treatments with 100% of ETc. Despite the treatments used with the PRD did not differ for the number of fruits and productivity, the use of the PRD with 40% of ETc allows higher water use efficiency with consequent increase in profitability for the producer and the rational water use, in agreement with the current relationship society-nature; decrease in production cost by the lowest amount of water placed on the ground and fewer pumping hours.

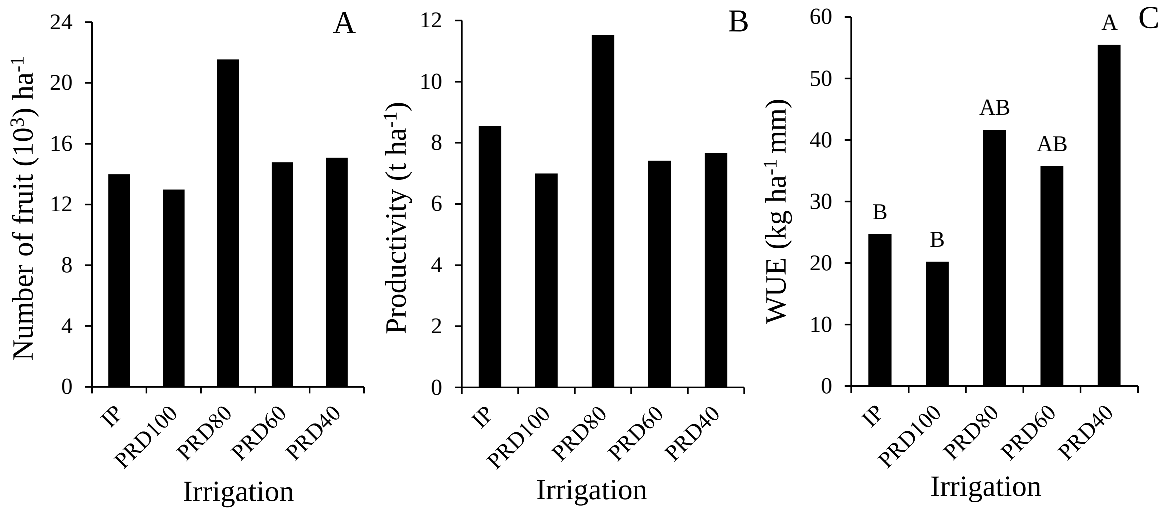

FIGURE 7. Number of fruits per hectare (A), productivity (B) and water use efficiency - WUE (C) on 'Tommy Atkins' mango tree with partial rootzone drying, PRD, every 15 days. Guanambi, BA, 2013. IP (full irrigation), PRD 40, 60, 80 and 100% ETc crop evapotranspiration. The coefficients of variation - CV (%) for the total number of fruits, total productivity and the WUE were 49.00, 47.37 and 45.61, respectively. Means followed by the same letter in the bar graph does not differ at 5% probability by Tukey test.

The effects of treatments in production and its components were analyzed considering the overall harvest. The analysis of variance indicated that the yield and the number of fruits per hectare were influenced by the reduction of the proposed irrigation depths (Figure 8). The regulated deficit irrigation with 50 and 75% of ETc on fruit set phase (PI) causes significant reduction of 37.47% and 44.66% in the number of fruits and 39.58% and 45.29% in productivity of 'Tommy Atkins' mango trees , when compared to treatment with full irrigation (100% ETc).

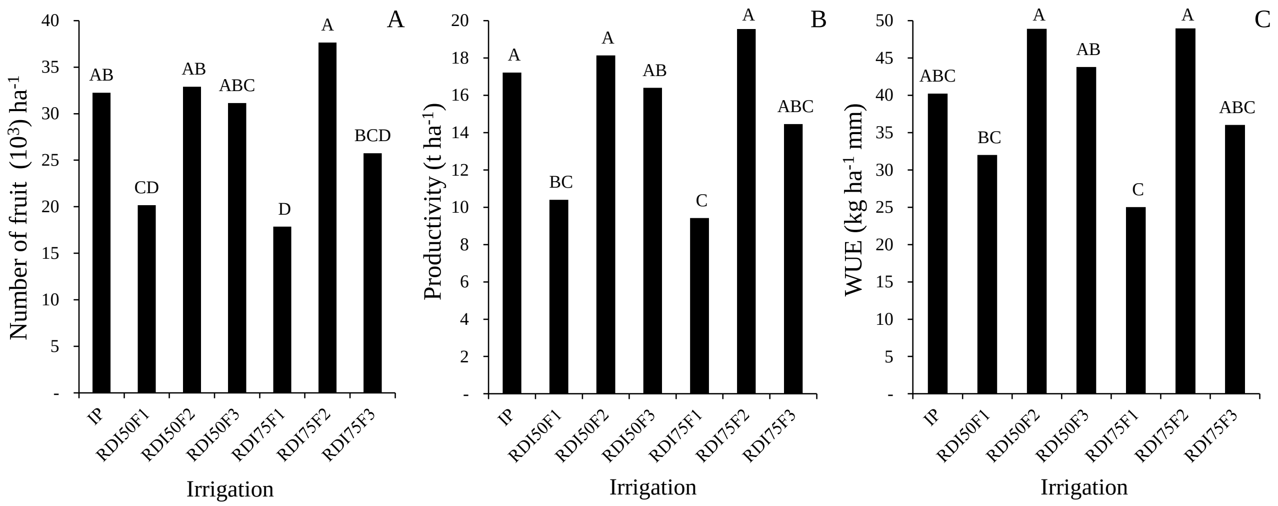

FIGURE 8. Number of fruits per hectare (A), productivity (B) and water use efficiency - WUE on 'Tommy Atkins' mango trees under regulated deficit irrigation, RDI. Guanambi, BA, 2013. Means followed by the same letter on the graphic bar does not differ at 5% probability by Tukey test. The coefficients of variation - CV (%) for the number of fruit, total productivity and WUE were 27.53, 28.20 and 22.83 respectively.

Moreover, the RDI with 50 and 75% of ETc in the expansion phase of the fruit (PII), and at physiological maturity phase (PIII) does not cause reduction in production. This behavior was possibly because the phase which extends from the end of the growth to physiologic ripening of fruits is less sensitive to water stress compared to the other phases when applied reduced irrigation, even though the plants develop adjustment mechanisms for performing full gas exchange in the later stages to water deficit, as discussed above.

When comparing the average yields of RDI75FII treatments, and treatment with full irrigation, it is observed that there was no significant difference, although there is a percentage difference of 13.5% higher on productivity in treatment with deficit. The irrigation management strategy with the lower irrigation depths focuses on water and energy savings, which helps to decrease the production cost. This percentage increase in production can be considerable in the marketing of fruit between harvests periods, with a concentration for better price paid for fruit.

The results of this study differ from those reported by COTRIM et al. (2011),which no significant differences at 5% probability on 'Tommy Atkins' mango tree productivity submitted to regulated deficit irrigation between treatments with 100, 80, 60, 40 and 30% of ETc under micro sprinkler systems and drip. The authors explained the results by rise of the water level in the study area, which prevented the effect of different irrigation depths. However, high variability inherent to the characteristic may also contribute to the explanation, since the productivities ranged to 77.9% for micro sprinkler (RDI to 60% of ETc phase II without irrigation) and 31.0% in the drip (full irrigation in three phases and without irrigation).

The water use efficiency was influenced by treatments with RDI. When looking at Figure 10, it is observed differences between treatments RDI 50% and 75% of ETc applied during the development of the fruits compared to treatments with the same irrigation depths, but imposed during the flowering phase. Considering the average of treatments, the most appropriate water use efficiency by the mango culture are observed when it adopts the use of RDI with 50% and 75% of

ETc in the second phase of development of the mango fruit. The use of RDI, with 50% and 75% of ETc in the flowering phase (RDI50FI and RDI75FI) express lower levels of WUE which reinforces the idea of the higher sensitivity of mango in the flowering phase for low levels of irrigation.

From the results, it is seen that the RDI enables satisfactory results both in the water economy as maximizing productivity. This was also observed by SANTOS (2014b) which emphasizes the use of irrigation depths RDI 50% of ETc in the maturing fruits phase more effective to WUE increase. Similar effects with different irrigation regimes were demonstrated by SPREER et al. (2009) who found that higher water use efficiency on mango subjected to deficit irrigation of 30 to 50%. These data differ from SILVA et al. (2009) that observed even though larger WUE values for reduced depths, this reduction was lower (90% of ETc.) compared to this study. COTRIM et al. (2011) although did not find a significant difference in productivity and fruit number showed an increase in water use efficiency in irrigation depths on 60% of ET_C.

CONCLUSIONS

1. Partial rootzone drying with 40% of ETc causes reduction in photosynthesis, carboxylation efficiency and quantum efficiency of photosynthesis at 8 a.m. compared to full irrigation and PRD 80% of ETc.

2. The phases of expansion and physiological ripeness of the fruit are more suitable for application of RDI with 50% and 75% of ETc with maintenance on mango productivity and higher water use efficiency;

3. The partial rootzone drying strategy, PRD every 15 days with 40% of ETc, provides higher WUE in mango tree and productivity maintenance.

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