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Morphophysiology and water relations of *Spondias* rootstocks under different irrigation frequencies

Morfofisiologia e relações hídricas de porta-enxertos de *Spondias* sob diferentes frequências de irrigação

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ABSTRACT - The semi-arid region of northeastern Brazil is characterized by scarcity of water for irrigation purposes due to long periods of drought, compromising the development of species such as *Spondias tuberosa* L. and *Spondias mombin* L., which, despite being considered drought tolerant, can have their yield negatively affected by low water availability. The objective of this study was to evaluate the morphophysiology, quantum efficiency and water relations of *S. tuberosa* and *S. mombin* rootstocks under different irrigation intervals in the semi-arid region of Paraíba, Brazil. The experimental design was carried out in randomized blocks, in a 5 × 2 factorial scheme, referring to 5 irrigation intervals - INT (1, 2, 3, 4 and 5 days after each irrigation event) and two species of the genus *Spondias* - SPC (*S. tuberosa* and *S. mombin*) with four replicates and three plants per plot, totaling 120 plants. Irrigation management with a five-day irrigation interval reduced gas exchange and growth of rootstocks of the *Spondias* species. The quantum efficiency of photosystem II of *Spondias* rootstocks (*S. tuberosa* and *S. mombin*) was not compromised when the plants were irrigated every two and four days. Irrigation every three days in the early stages of development of *Spondias* species can be used with the lowest losses in gas exchange and growth of rootstocks.

Keywords: Irrigation frequency. *Spondias tuberosa*. *Spondias mombin*. Water scarcity.

RESUMO - O semiárido nordestino é caracterizado pela escassez hídrica para fins de irrigação em decorrência de longos períodos de estiagem, comprometendo o desenvolvimento de espécies como *Spondias tuberosa* e a *Spondias mombin*, que apesar de serem considerados tolerantes a seca, podem ter seu rendimento afetado negativamente pela baixa disponibilidade de água. Objetivou-se com este trabalho avaliar a morfofisiologia, a eficiência quântica e as relações hídricas de porta-enxertos de *S. tuberosa* e *S. mombin* sob diferentes turnos de rega no semiárido paraibano. O delineamento experimental realizado em blocos ao acaso, em esquema fatorial 5 × 2, referentes a 5 turnos de rega - INT (1, 2, 3, 4 e 5 dias após cada evento de irrigação) e duas espécies do gênero *Spondias* - SPC (*S. tuberosa* e *S. mombin*) com quatro repetições e três plantas por parcela, totalizando 120 plantas. O manejo da irrigação com turno de rega de cinco dias reduziu as trocas gasosas e o crescimento dos porta-enxertos das espécies de *Spondias*. A eficiência quântica do fotossistema II de porta-enxertos de *Spondias* (*S. tuberosa* e *S. mombin*) não é comprometida quando as plantas foram irrigadas a cada dois e quatro dias. A irrigação a cada três dias nas fases iniciais do desenvolvimento das espécies *Spondias* pode ser utilizada com as menores perdas nas trocas gasosas e no crescimento dos porta-enxertos.

Palavras-chave: Escassez hídrica. *Spondias tuberosa*. *Spondias mombin*. Turno de rega.

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INTRODUCTION

The expansion of fruit growing in the Brazilian Northeast can be attributed to climatic characteristics such as photoperiod and relative air humidity. However, this region faces limitations related to water availability, involving quantitative and qualitative aspects, causing restrictions of use for human and animal consumption and for irrigation of crops (BABOEV et al., 2017).

Water scarcity results from irregular rainfall distribution throughout the year, ranging on average from 250 to 800 mm, and high evapotranspiration rates, ranging from 175 to 595 mm per year, which results in an unfavorable water balance (FAUSTINO et al., 2016; SOARES et al., 2023). In this context, it is necessary to adapt to the reality of the region and deal with the problem by introducing technologies and techniques aimed at mitigating the deleterious effects of water deficit.

Among the species present in the Caatinga, *Spondias tuberosa* (Brazil plum) and *Spondias mombin* (Yellow mombin) stand out. These species are tropical fruit plants, native to northeastern Brazil, which belong to the Anacardiaceae family and have great prospects for the production of exotic fruits. Their fruits can be consumed in various ways, for instance, in the form of pulp, juices and ice cream. Their roots, leaves and seeds are used in medicine (SOUSA et al., 2017).

The low availability of water to plants causes several physiological and morphological problems, leading to decreased development of most agricultural species. As an adaptive strategy, plants close their stomata to avoid water loss to the atmosphere; with the decline in transpiration, however, this adjustment causes thermal and oxidative stress, compromises photosynthesis, due to the drop in CO_2 uptake, and produces damage to the photosynthetic apparatus. In response to stress, plants reduce the production and allocation of photoassimilates necessary for growth and development (FIGUEIREDO et al., 2019).

The genus *Spondias*, in general, shows good performance under the edaphoclimatic conditions of the semi-arid region of northeastern Brazil, so plants in this genus are considered drought-resistant. However, there is a maximum potential for development of the species under low water availability, with possible reduction from this level (CAVALCANTI; RESENDE; BRITO, 2011). Knowledge on their limitations and potentialities in the efficient use of water can promote better exploitation and expansion of this crop in regions with water deficit. Proper management of irrigation interval can favor water reserve in the soil to meet the water requirements of plants (SILVA et al., 2020).

In order to ensure the success in the use of water by plants through irrigation management, it is necessary to adopt methodologies that establish the ideal irrigation interval, in order to avoid wasting this resource (BAYER, 2020). However, irrigation interval adequacy is dependent on soil water storage capacity and water consumption of the plants and may vary between species (SILVA; FRANÇA, 2018). The objective of this study was to evaluate the morphophysiology, quantum efficiency and water relations of rootstocks of *S. tuberosa* and *S. mombin* under different irrigation intervals in the semi-arid region of Paraíba, Brazil.

MATERIAL AND METHODS

The experiment was conducted in a protected environment (greenhouse) at the Center for Sciences and Agri -Food Technology - CCTA of the Federal University of Campina Grande - UFCG, located in the municipality of Pombal, Paraíba, Brazil, at the geographical coordinates 6º47’20” S latitude and 37º48’01” W longitude, at an altitude of 194 m. Figure 1 shows the meteorological data along the experiment between February 8, 2019 and June 16, 2019.

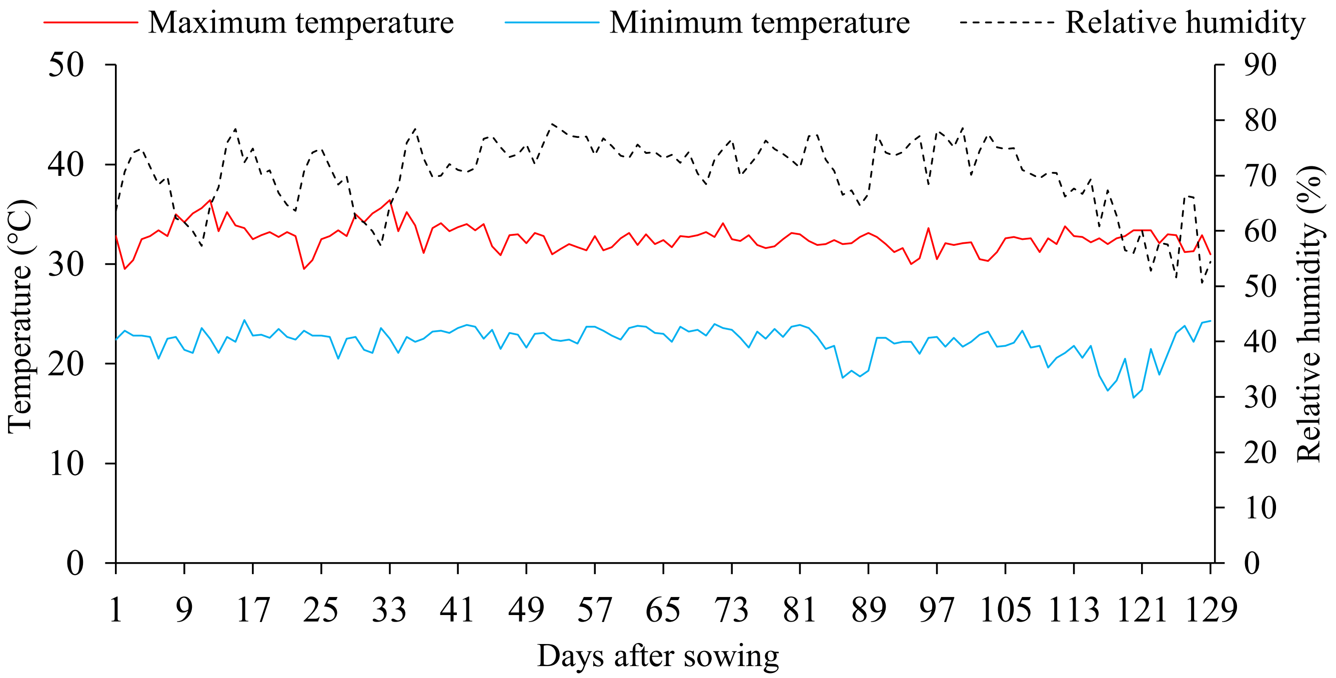

Figure 1. Data of maximum and minimum temperature and relative humidity during the experimental period.

A randomized block design was used, in 5 × 2 factorial scheme, referring to 5 irrigation intervals - INT (irrigation performed at intervals of 1, 2, 3, 4 and 5 days) and two species - SPC, *S. tuberosa* and *S. mombin*, with four replicates and three plants per plot, totaling 120 plants.

Sowing was carried out in tubes, with capacity for 288 mL of substrate. After establishment of the seedlings, at 45 days after sowing (DAS), they were transplanted into 3.4-L plastic bags. Subsequently, grafting and seedling production were performed for the establishment in the field. The tubes were filled with substrate consisting of two parts of soil, one part of cattle manure and one part of washed sand in a 2:1:1 ratio (volume basis). Physical-hydraulic and chemical attributes were determined according to the methodology of Teixeira et al. (2017), and the results are shown in Table 1.

Table 1. Physical-hydraulic and chemical characteristics of the soil used in the experiment.

Density	Total Porosity	Moisture (%)		Available water	Sorption Complex					
					Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	pH_{sp}	EC_{se}
($kg\ dm^{-3}$)	(%)	0.33 atm	15 atm	(%)	---------------- ($cmol_c\ kg^{-1}$) ----------------				-	($dS\ m^{-1}$)
1.56	42.00	12.85	4.66	8.19	3.67	2.76	1.1	0.26	8.98	0.42

Ca^{2+} and Mg^{2+} extracted with 1 mol L^{-1} KCl at pH 7.0; Na^{+} and K^{+} extracted with 1 mol L^{-1} NH_4OAc; P – Mehlich 1 extractant; pH_{sp} – pH of the saturation paste; and EC_{se} – electrical conductivity of the saturation extract.

Fertilization with NPK was performed following the recommendations of Novais, Neves and Barros (1991) for pot experiments, corresponding to 100, 150 and 300 mg per kg of soil for N, K_2O and P_2O_5, respectively. The nutritional sources used were urea, monoammonium phosphate and potassium chloride. Top-dressing fertilization was applied at 15 days after transplantation (DAT). Subsequently, fertilization was carried out via irrigation water, split into six portions, applied fortnightly. Micronutrients were applied through the leaves every 20 days, using Niphokan®. The seedlings were arranged on metal benches at 0.8 m height from the ground.

In the first 15 DAT, the seedlings received water every day and, from this period, the irrigation intervals were applied, until 129 DAT. For each irrigation interval, the volume to be applied was determined by weighing lysimetry, and the irrigation depth, obtained by difference according to Equation 1, was replaced every 15 days.

$$\mathrm{Vi} = [(\mathrm{Wi} - \mathrm{Wf}) \times 1] \quad (1)$$

Where: Vi= volume of irrigation per container (L);
Wi= initial weight of container before draining (kg);
Wf= final weight of container after draining (kg); and
Constant 1 = specific weight of water.

Pest and disease control was performed as needed. In the control of invasive plants, manual weeding was carried out during the experimental period to avoid interspecific competition for water and nutrients, favoring the development of the crop.

At 129 DAT, gas exchange was determined by measuring the following variables: stomatal conductance - *gs* ($mol\ CO_2\ m^{-2}\ s^{-1}$); transpiration - *E* ($mmol\ H_2O\ m^{-2}\ s^{-1}$); CO_2 assimilation rate - *A* ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$); and internal CO_2 concentration (*Ci*) ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$). These data were then used to estimate the instantaneous carboxylation efficiency - *CEi* (A/Ci) [($\mu mol\ CO_2\ m^{-2}\ s^{-1}$) ($\mu mol\ CO_2\ m^{-2}\ s^{-1})^{-1}$] and instantaneous water use efficiency - WUEi [($\mu mol\ CO_2\ m^{-2}\ s^{-1}$) ($mmol\ H_2O\ m^{-2}\ s^{-1})^{-1}$]. The analyses were performed with a plant gas exchange meter, containing an infrared gas analyzer - IRGA (Infrared Gas Analyser, LCpro - SD model, from ADC BioScientific, UK). Readings were performed at 7:00 a.m. on the third fully expanded leaf counted from the apical bud. The analyses were carried out under natural conditions of air temperature, CO_2 concentration and using an artificial radiation source of 1200 $\mu mol\ m^{-2}\ s^{-1}$ (FERNANDES et al., 2021).

At 129 DAT, chlorophyll *a* fluorescence evaluations were performed at 7:00 a.m. using leaf clips and, after a period of 30 minutes of adaptation to the dark, initial fluorescence - F_0, maximum fluorescence - Fm, variable fluorescence - Fv, and quantum efficiency of photosystem II - Fv/Fm were determined, all with a pulse-amplitude modulated fluorimeter (PAM fluorometer - OS5p Model, Opti-Science/ Hudson, NY, USA).

Growth of the *Spondias* species was determined based on the following variables: number of leaves (NL), obtained by counting, considering mature leaves with length greater than 3 cm and with characteristic color of the species; plant height (PH), considering the length of the aerial part from the plant collar to the apical bud of the main branch, expressed in centimeters (cm); and stem diameter (SD), determined at 2 cm from the soil using a digital caliper, with readings expressed in millimeters (mm).

To determine the relative water content (RWC), at 129 DAT, the leaves were collected and their fresh mass (FM) was determined. Then, the samples were placed in plastic bags, immersed in distilled water and stored for 24 hours. Then, excess water was removed with paper towels to determine the turgid mass (TM); subsequently, the samples were dried in an oven with air circulation (temperature ≈ 65 ºC ± 3 ºC, until reaching constant mass) to obtain the dry mass (DM). RWC was obtained according to Lima et al. (2019), using Equation 2:

$$\mathrm{RWC} = \frac{\mathrm{FM} - \mathrm{DM}}{\mathrm{TM} - \mathrm{DM}} \times 100 \quad (2)$$

where:
RWC = Relative water content (%);
FM= leaf fresh mass (g);
TM= leaf turgid mass (g); and
DM = leaf dry mass (g).

At the end of the experiment, accumulated water consumption (WC) was determined, calculated from the sum of daily water consumption, per experimental unit, recorded along the 129 days of the experiment. Average water consumption was calculated by the arithmetic mean of each treatment applied.

The data obtained were evaluated by analysis of variance by the F test. In cases of significance, Tukey test ($p \leq 0.05$) was performed for data related to irrigation intervals and species (FERREIRA, 2019).

RESULTS AND DISCUSSION

There were significant effects of the interaction between irrigation intervals and *Spondias* species on CO_2 assimilation rate and instantaneous carboxylation efficiency ($p \leq 0.01$). Individually, a significant difference ($p \leq 0.05$) was observed between the irrigation intervals for stomatal conductance, transpiration and internal CO_2 concentration. In the *Spondias* species, there was a significant difference for internal CO_2 concentration and instantaneous water use efficiency ($p \leq 0.05$) (Table 2).

Table 2. Summary of analyses of variance for stomatal conductance (*gs* - mol CO_2 m^{-2} s^{-1}), transpiration (*E* - mmol H_2O m^{-2} s^{-1}), internal CO_2 concentration (*Ci* - µmol CO_2 mol^{-1}), CO_2 assimilation rate (*A* - µmol CO_2 m^{-2} s^{-1}), instantaneous water use efficiency [*WUEi* - (µmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$] and instantaneous carboxylation efficiency [*CEi* - (µmol CO_2 m^{-2} s^{-1}) (µmol CO_2 m^{-2} s^{-1})$^{-1}$] of *Spondias* species (SPC) under different irrigation intervals (INT), at 129 days after the transplantation.

Source of variation	DF	Mean Square					
		gs	*E*	*Ci*	*A*	*WUEi*	*CEi*
Irrigation intervals (INT)	4	0.0018^{*}	0.67^{*}	2828.75^{*}	12.94^{**}	0.71^{ns}	0.0005^{**}
Species (SPC)	1	0.0002^{ns}	0.21^{ns}	7590.02^{**}	58.12^{**}	11.47^{**}	0.0034^{**}
INT × SPC	4	0.0002^{ns}	0.12^{ns}	2152.40^{ns}	11.79^{**}	2.19^{ns}	0.0005^{**}
Blocks	3	0.0016^{ns}	0.63^{ns}	1404.42^{ns}	4.77^{ns}	1.56^{ns}	0.0001^{ns}
Residual	27	0.0005	0.23	1045.90	2.85	0.81	0.0001
CV (%)		31.06	27.12	16.12	23.73	21.89	29.05
Species							
S. tuberosa		0.075 a[1]	1.69 a	214.40 a	5.91 b	3.59 b	0.027 b
S. mombin		0.080 a	1.84 a	186.85 b	8.32 a	4.56 a	0.046 a

DF - degrees of freedom; CV (%) - coefficient of variation; **significant at 0.01 probability level; *significant at 0.05 probability level; ^{ns}not significant. [1]Equal uppercase letters indicate no significant difference between *Spondias* species (Tukey, p≤0.05).

Among the *Spondias* species, a higher mean of internal CO_2 concentration (*Ci*) was found in *S. tuberosa* (241.40 CO_2 m^{-2} s^{-1}), exceeding by 14.74% the *Ci* of *S. mombin* plants (186.85 µmol mol^{-1}) (Table 2). The internal CO_2 concentration is variable among species as it is dependent on the anatomy of the leaf mesophyll (DAMATTA et al., 2016). Normally, the increase in CO_2 assimilation rate leads to reductions in the internal CO_2 concentration (PINHEIRO et al., 2022), as observed in the rootstocks of *S. mombin* with a CO_2 assimilation rate of 8.32 µmol CO_2 m^{-2} s^{-1} with an increment of 40.72% compared to *S. tuberosa* (Table 2).

Among the *Spondias* species, the instantaneous water use efficiency (*WUEi*) was higher in *S. mombin*, 4.56 (µmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$, an increase of 27.01% when compared to *S. tuberosa*, which had *WUEi* of 3.59 (µmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$ (Table 2). Leaf gas exchange is regulated by the stomata, so the absorption of CO_2 from the external environment causes water loss and also restricts the entry of CO_2 into the substomatal chamber. In this context, it is extremely important that plants under water stress conditions maintain greater water use efficiency, that is, that they absorb the maximum of CO_2 with minimum water loss to the atmosphere (BRITO et al., 2012).

For the interaction between species and irrigation intervals, the stomatal conductance decreased by 67.27% when the five-day irrigation interval was adopted, compared to plants irrigated daily (Figure 2A). Due to the partial closure of the stomata, leaf transpiration (*E*) was reduced when the plants were irrigated every five days, with a decrease of 36.67% (0.77 mmol H_2O m^{-2} s^{-1}) compared to those subjected to daily irrigation (Figure 2B).

The longest interval between irrigations (5 days) resulted in water deficit, but promoted the development of adaptive mechanisms in both species aiming at survival to this stressful condition. Among the adaptive responses, stomatal closure is the first line of defense against dehydration, through the regulation of stomatal conductance, which is a key phenomenon in plants for preventing dehydration during stress (SILVA et al., 2019). Consequently, there is reduction in transpiration and accumulation of plant energy, which, if not safely dissipated, can cause overexcitation in the reaction center of photosystem II (PINHEIRO; CHAVES, 2011; DIAS et al., 2019).

When analyzing the internal CO_2 concentration (*Ci*), the highest mean was observed under the daily irrigation interval, 227.75 µmol CO_2 m^{-2} s^{-1}, but it did not differ from those values found under the irrigation intervals of two (INT2), three (INT3) and four (INT4) days; however, plants under the five-day irrigation interval, at 129 DAS, had an internal CO_2 concentration on average 27.05% lower when compared to those irrigated daily (Figure 2C).

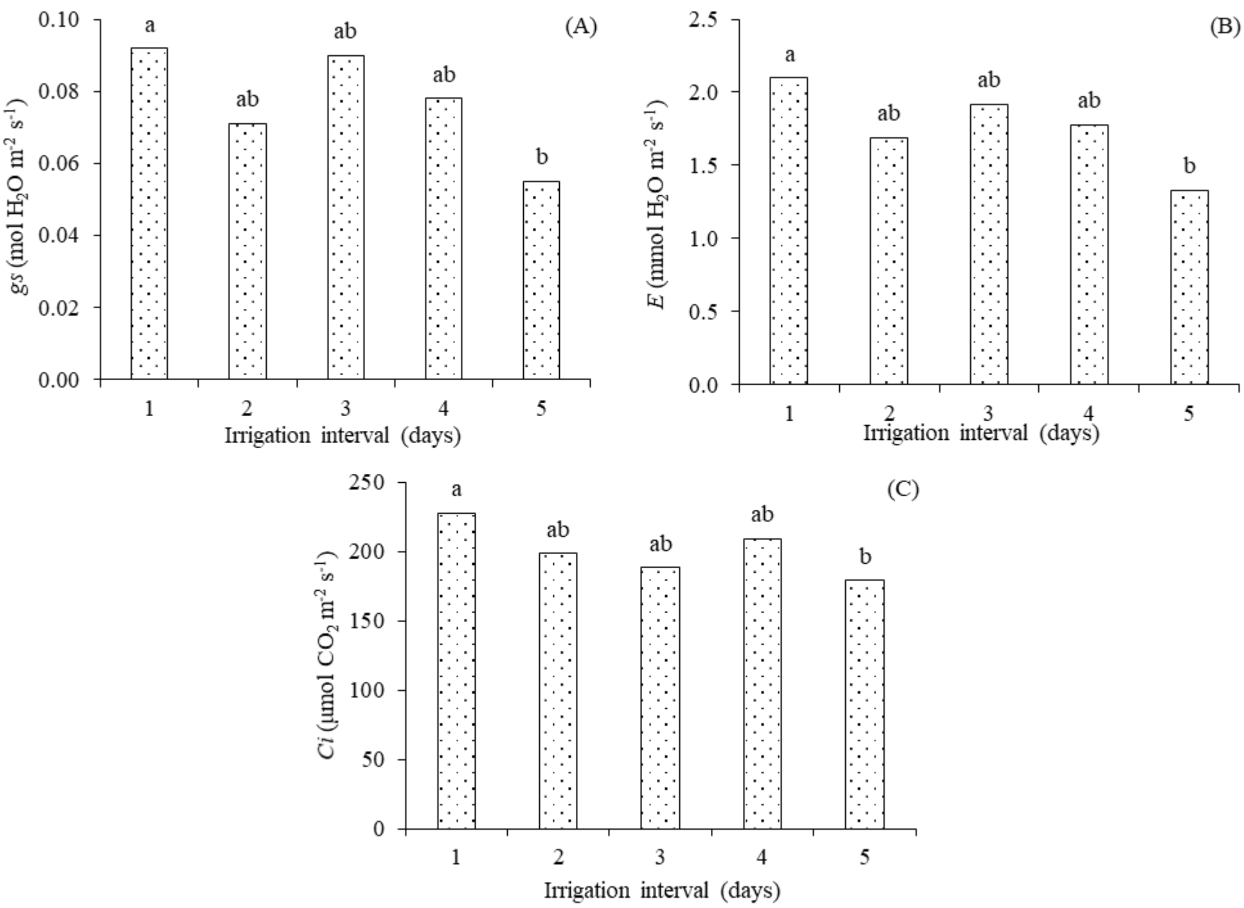

Figure 2. Stomatal conductance - *gs* (A), transpiration - *E* (B) and internal CO_2 concentration - *Ci* (C) of *Spondias* species as a function of irrigation intervals, at 129 days after transplantation. 1, 2, 3, 4 and 5 = alternating irrigation interval in days. Lowercase letters between irrigation intervals do not differ by Tukey test, p≤0.05.

The reductions recorded in the internal CO_2 concentration are consequences of the decreases observed in the stomatal conductance and transpiration of *Spondias* species, which are justified by the fact that during the gas exchange process, the absorption of CO_2 leads to loss of water and, in the opposite direction, the reduction of this water loss restricts CO_2 assimilation and consequently results in a higher internal CO_2 concentration (ANDRADE et al., 2018; SOARES et al., 2018).

Figure 3A shows the means resulting from the decomposition of the INT × SPC interaction, showing a higher CO_2 assimilation rate in *S. tuberosa* rootstocks when irrigated daily with 8.81 μmol CO_2 m^{-2} s^{-1}; for *S. mombin* rootstocks, irrigations performed every three days (INT3) resulted in an increase of 47.11% in CO_2 assimilation rate compared to plants irrigated daily (INT1). Differences between *Spondias* species were observed from the three-day irrigation interval; *S. mombin* rootstocks had higher CO_2 assimilation rate, with increments of 82.36, 58.68 and 112.90% compared to *S. tuberosa*, when irrigation intervals of three, four and five days were adopted, respectively (Figure 3A). Plants adapted to water deficit have developed specific mechanisms of acclimatization to stress that involve the efficient use of water, maintaining a high CO_2 assimilation rate even with the partial closure of the stomata (FLEXAS et al., 2016).

S. tuberosa plants, when irrigated daily, had an increment in instantaneous carboxylation efficiency (*CEi*) of 59.45%, when compared to plants irrigated every five days (INT5). However, among the rootstocks of *S. mombin* the instantaneous carboxylation efficiency was higher when the three-day irrigation interval was adopted [0.067 (μmol CO_2 m^{-2} s^{-1}) (μmol CO_2 m^{-2} s^{-1})$^{-1}$], while reductions of 55.22, 29.85, 37.31 and 36.56% were observed when irrigation intervals of one, two, four and five days were adopted, respectively (Figure 3B).

Among the *Spondias* species, *CEi* was lower in *S. tuberosa* than in *S. mombin* plants under irrigation intervals of two, three, four and five days (Figure 3B). This is a consequence of the high CO_2 assimilation of *S. mombin*, due to the reduction of CO_2 in the substomatal chamber, because if *Ci* decreases due to the increase in photosynthetic activity or partial closure of the stomata, there is an increase in the *CEi* ratio.

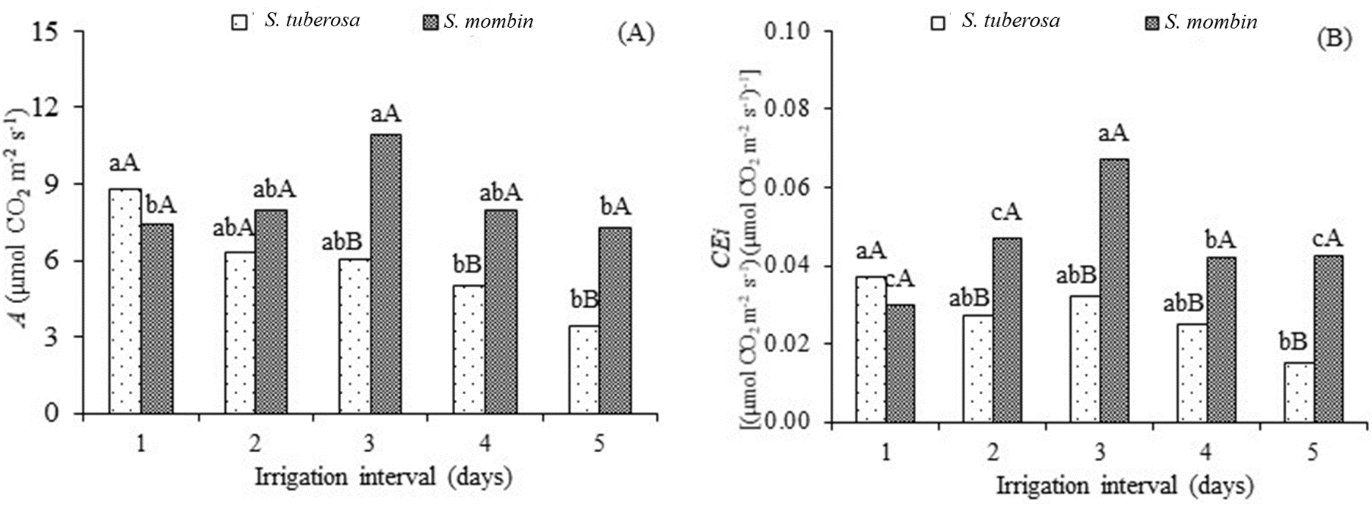

Figure 3. CO_2 assimilation rate - *A* (A) and instantaneous carboxylation efficiency - *CEi* (B) of *Spondias* species as a function of irrigation intervals, at 129 days after transplantation. 1, 2, 3, 4 and 5 = alternating irrigation interval in days. Lowercase letters between irrigation intervals and uppercase letters between *Spondias* species do not differ by Tukey test, p≤0.05.

Table 3 shows a significant effect of the irrigation interval factor on initial fluorescence (F_0) and quantum efficiency of photosystem II (Fv/Fm) ($p \leq 0.01$). For *Spondias* species, there were significant effects on all fluorescence variables. Regarding the interaction between the factors, no significant effect was found for the variables analyzed, at 129 DAS (Table 3).

Table 3. Summary of the analysis of variance for initial fluorescence (F_0), maximum fluorescence (Fm), variable fluorescence (Fv) and quantum efficiency of photosystem II (Fv/Fm) of *Spondias* species (SPC) under different irrigation intervals (INT), at 129 days after transplantation.

Source of variation	DF	Mean Square			
		F_0	Fm	Fv	Fv/Fm
Irrigation intervals (INT)	4	10781.83**	11632.47^{ns}	2785.08^{ns}	0.0004**
Species (SPC)	1	207792.22**	1583244.10**	670033.22**	0.0023**
INT× SPC	4	1513.03^{ns}	24434.85^{ns}	20065.53^{ns}	0.0001^{ns}
Blocks	3	1335.09^{ns}	36828.86^{ns}	20704.55^{ns}	0.0003^{ns}
Residual	27	2227.18	18464.31	12499.50	0.0001
CV (%)		6.28	3.90	4.09	1.37
Species					
S. tuberosa		824.10 a[1]	3682.75 a	2863.70 a	0.7771 b
S. mombin		679.95 b	3284.85 b	2604.85 b	0.7925 a

DF - degrees of freedom; CV (%) - coefficient of variation; **significant at 0.01 probability level; *significant at 0.05 probability level; ^{ns}not significant. [1]Equal uppercase letters indicate no significant difference between *Spondias* species (Tukey, p≤0.05).

Among the *Spondias* species analyzed, regardless of the irrigation interval, *S. tuberosa* had the highest initial fluorescence, maximum fluorescence and variable fluorescence. On the other hand, the quantum efficiency of photosystem II (Fv/Fm) of *S. mombin* (0.79) was higher than the value observed in *S. tuberosa* (0.77) (Table 3). Thus, it can be seen that *S. mombin* had greater physiological potential, which may indicate high efficiency in the use of radiation and greater activity of light absorption and transfer of photosynthetic pigments (FERRAZ et al., 2014).

The *Spondias* species had higher initial fluorescence (F_0) (797.62) when the five-day irrigation interval (INT5) was adopted, with increments of 10.95 and 11.28% compared to the plants under irrigation intervals of two and four days, respectively (Figure 4A). Thus, the increase in F_0 may be a consequence of damage to the reaction center of PSII or reduction of the ability to transfer the excitation energy from the antenna to the reaction center (SÁ et al., 2018).

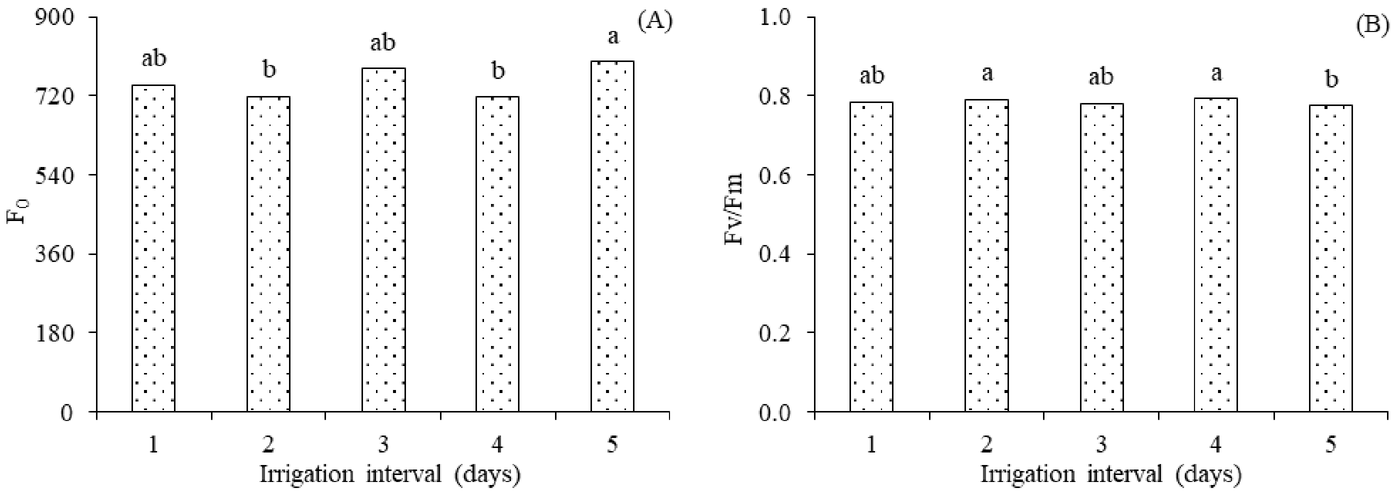

Figure 4. Initial fluorescence - F_0 (A) and quantum efficiency of photosystem II - Fv/Fm (B) of *Spondias* species as a function of irrigation intervals, at 129 days after transplantation. 1, 2, 3, 4 and 5 = alternating irrigation interval in days. Lowercase letters between irrigation intervals do not differ by Tukey test, p≤0.05.

However, the damage to the chlorophylls of the antenna complex was not sufficient to cause greater reductions in Fv/Fm, and the highest means were obtained under the irrigation intervals of two and four days, with quantum efficiency of photosystem II of 0.79 (Figure 4B). Stability and maintenance of pigments are required for better efficiency in the photosynthetic process, being one of the characteristics of tolerance to drought and heat, besides contributing to the maintenance of plant production (NANKISHORE; FARRELL, 2016).

According to data from the analysis of variance shown in Table 4, the interaction between the factors irrigation intervals and *Spondias* species significantly influenced plant height, stem diameter and water consumption. There was a significant effect of the *Spondias* species on the number of leaves and relative water content (p ≤ 0.01). When the two *Spondias* species were studied individually, it was observed that the rootstocks of *S. mombin* had a higher number of leaves (29.30 leaves per plant), differing from those of *S. tuberosa*, which had a reduction in the number of leaves of 73.88% (Table 4).

It is worth pointing out that the greater number of leaves of *S. mombin* is directly related to the photosynthetic process, through the interception of light energy. As photosynthesis depends on leaf area, the faster the plant reaches a higher leaf area index and the longer it remains in photosynthetic activity, the higher the yield (SOARES et al., 2018).

Table 4. Summary of the analysis of variance for number of leaves (NL), plant height (PH - cm), stem diameter (SD - mm), relative water content (RWC - %) and water consumption (WC - L) of *Spondias* species (SPC) under different irrigation intervals (INT), at 129 days after transplantation.

Source of variation	DF	Mean Square				
		NL	PH	SD	RWC	WC
Irrigation intervals (INT)	4	4.70^{ns}	149.26^{ns}	4.49**	398.81^{ns}	76.43**
Species (SPC)	1	1550.02**	375.15^{ns}	30.99*	2184.04**	107792.22**
INT × SPC	4	12.44^{ns}	448.32*	7.14**	420.58^{ns}	76.43**
Blocks	3	7.07^{ns}	626.77^{ns}	2.36^{ns}	485.18^{ns}	227792.22^{ns}
Residual	27	8.68	144.84	1.32	204.67	17.89
CV (%)		12.77	20.42	12.59	16.96	27.85
Species						
S. tuberosa		16.85 b[1]	55.87 a	10.02 a	91.73 a	16.54 a
S. mombin		29.30 a	62.00 a	8.26 b	76.95 b	13.83 b

DF - degrees of freedom; CV (%) - coefficient of variation; **significant at 0.01 probability level; *significant at 0.05 probability level; ^{ns}not significant. [1]Equal uppercase letters indicate no significant difference between *Spondias* species (Tukey, p≤0.05).

For the relative water content (RWC) as a function of the different *Spondias* species (Table 4), its values were higher in *S. tuberosa* (91.73%), while *S. mombin* had a decrease of 19.20% in its RWC. This higher RWC observed in *S. tuberosa* is possibly related to the high capacity for storage of water, minerals and other important solutes for the maintenance of a favorable water balance in a situation of water deficit (CRUZ; ANDRADE; FEITOSA, 2016).

S. mombin showed similar plant height under the different irrigation intervals (Figure 5A), with differences between *Spondias* species only under the three-day irrigation interval, for which *S. mombin* showed an increase of 53.58% when compared to *S. tuberosa*. Decreases were observed in the PH of *S. tuberosa* caused by the irrigation intervals longer than three days, with a prominent reduction under the three-day irrigation interval, equal to 52.98%, compared to plants irrigated daily (Figure 5A). It is evident from the results obtained that the damage induced by water deficit was dependent on the characteristics of each species, since some species can adapt to water deficit by modifying the levels of solutes within the cells, so stomatal opening and physiological activities can be maintained under low leaf water potential (KUMAGAI et al., 2015).

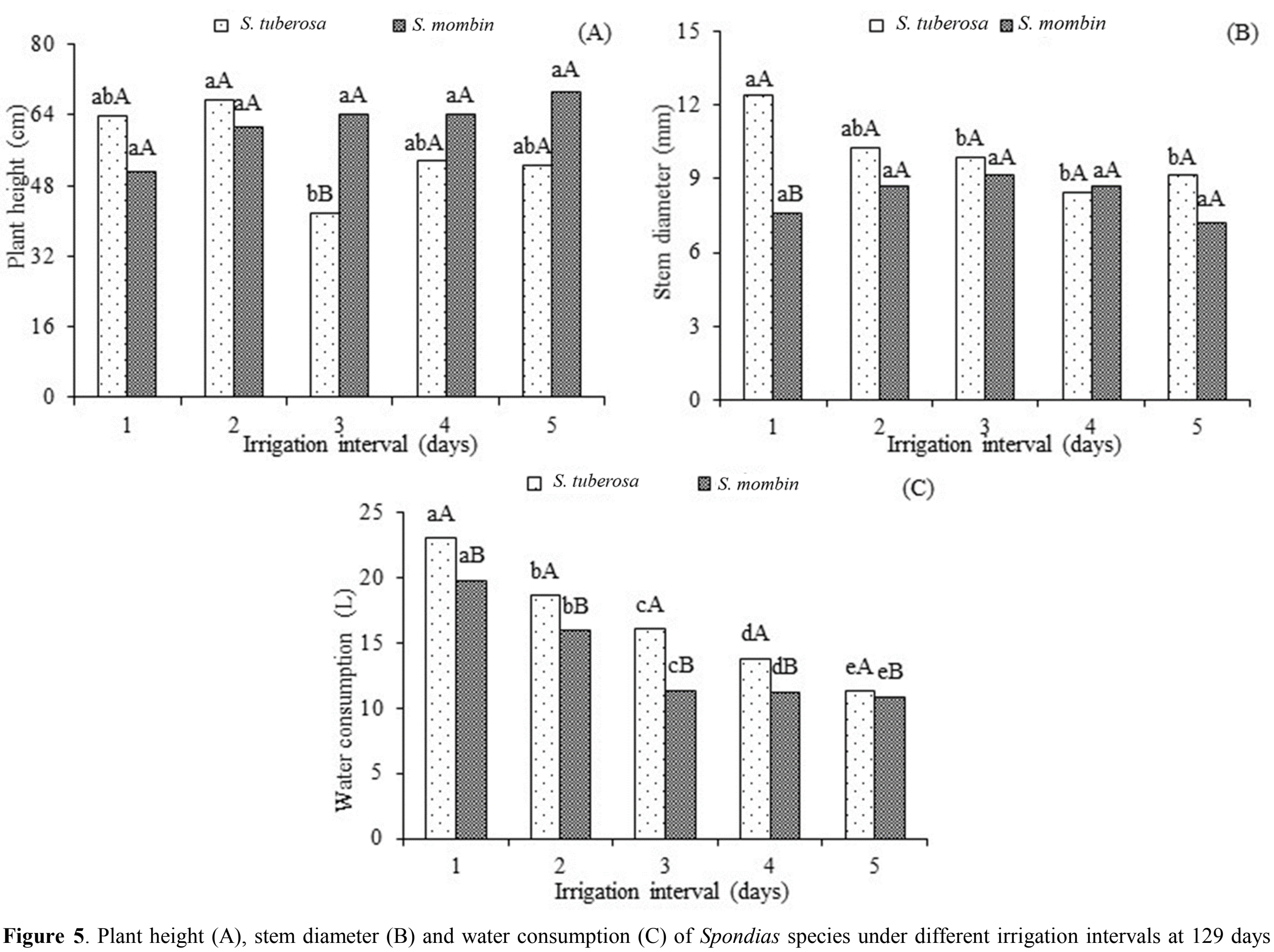

Figure 5. Plant height (A), stem diameter (B) and water consumption (C) of *Spondias* species under different irrigation intervals at 129 days after transplantation. 1, 2, 3, 4 and 5 = alternating irrigation interval in days. Lowercase letters between irrigation intervals and uppercase letters between *Spondias* species do not differ by Tukey test, p≤0.05.

An analysis of the irrigation intervals considering each *Spondias* species studied at 129 DAS (Figure 5B) shows that stem diameter (SD) was similar between the species, but the daily irrigation interval (INT1) caused a difference in SD, with reduction of 63.15% for *S. mombin* when compared to *S. tuberosa* rootstocks. The SD of *S. mombin* rootstocks was similar between the irrigation intervals adopted. For *S. tuberosa* rootstocks, reductions in SD were observed from the third day of irrigation, equal to 9.89, 8.45 and 9.12 mm under the irrigation intervals of three, four and five days, respectively (Figure 5B). However, a condition of normality of the data is observed, since the highest percentage of grafting success occurs with stem diameters ranging between 7.5 and 10 mm, so the SD of the *Spondias* species rootstocks under different irrigation intervals are suitable for grafting (GOMES et al., 2010).

Water consumption (WC) varied, following the same trend observed in the relative water content, and the means comparison test (Figure 5C) showed reductions in WC of 16.39, 16.54, 41.44, 22.77 and 4.32% in *S. mombin* plants subjected to the different irrigation intervals compared to *S. tuberosa*. As observed for the relative water content, there is a higher WC in the rootstocks of *S. tuberosa*, equal to 23 L when irrigated daily (Figure 5C). The increase of water consumption in *Spondias* plants may be associated with greater accumulation of organic and inorganic solutes aimed at reducing the water potential in the plant and thus ensuring the absorption of water and nutrients under water deficit (LIMA et al., 2020).

CONCLUSIONS

Irrigation management with a five-day irrigation interval reduces gas exchange and growth of rootstocks of *Spondias* species.

Quantum efficiency of photosystem II in the rootstocks is not compromised when the plants are irrigated every two and four days for both species.

Irrigation every three days in the early stages of development of *Spondias* species can be used with the lowest losses in gas exchange and growth of rootstocks.

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