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IS IT POSSIBLE TO SAVE WATER WITHOUT LOSING QUALITY IN THE GUANANDI SEEDLING PRODUCTION?

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1 ABSTRACT

In this study we examined if the irrigation depths (8, 11 and 14 mm), applied daily, splitted in two frequencies (two and four times a day) affect the seedling quality of *Calophyllum brasiliense* Cambess. (Guanandi) at nursery and initial development after planting in pot. The 11 mm irrigation depth produces the same amount of seedlings with suitable root systems for planting as the 14 mm irrigation depth and save 21% of water. The 11 mm irrigation depth, splitted in two times a day, compared to 14 mm irrigation depth, produces higher or equal morphological development, which continues after planting.

Keywords: *Calophyllum brasiliense*, irrigation depth, irrigation frequency, forest nurseries

SILVA, R. B. G.; SILVA, M. R.
É POSSÍVEL ECONOMIZAR ÁGUA SEM PERDER A QUALIDADE NA PRODUÇÃO DE MUDAS DE GUANANDI?

2 RESUMO

Neste estudo examinamos se as lâminas de irrigação (8, 11 e 14 mm), aplicadas diariamente, divididas em duas frequências (duas e quatro vezes ao dia) afetam a qualidade de mudas de *Calophyllum brasiliense* Cambess. (Guanandi) no viveiro e o desenvolvimento inicial após o plantio em vaso. A lâmina de irrigação 11 mm produz a mesma quantidade de mudas com sistemas radiculares aptos ao plantio que a lâmina de 14 mm e economiza 21% de água. A lâmina de irrigação 11 mm, dividida em duas vezes ao dia, comparada à lâmina de 14 mm, produz maior ou igual desenvolvimento morfológico, que se mantém após o plantio.

Palavras-chave: *Calophyllum brasiliense*, lâmina de irrigação, frequência de irrigação, viveiros florestais

3 INTRODUCTION

There is an increase in interest to establish forest plantations for timber production and for conservation-related reasons (ROSS-DAVIS et al., 2005). *Calophyllum brasiliense*

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Cambess. (Guanandi) species is recommended to plant in degraded riparian areas, soils permanently flooded and commercially reforested areas (CARVALHO, 2003).

To optimize plantings it is important to improve the morphological, physiological, and genetic quality of seedlings (WILSON; JACOBS, 2006).Under harsh conditions it has become increasingly obvious that a change of focus towards seedling quality is needed (LINDQVIST; ONG, 2005).

In nurseries, the main factors that affect the development and quality of seedlings are the quality of its genetic materials, water management, nutrition, the type of container and the substrates used (SILVA; SIMÕES; SILVA, 2012). The purpose of water management is to artificially supply plant water requirement, promoting seedlings quality in shorter production time (IRMAK et al., 2001; MORAIS et al., 2012). The irrigation frequency and amount of water applied on most commercial nurseries is based on personal experience, or increasingly on automated time clock systems (BEESON JR, 2004). In Brazil, the most common irrigation method in forest nurseries is via micro-sprinkler and the average irrigation depth is around 14 mm, which depending on the species, climate, type of substrate and container size may be considered excessive.

Under or overwatering of seedlings may have adverse consequences. Overwatering may lead to nutrient leaching which may affect environmental quality and increase production costs, while an under watering can impose a water deficit, deleteriously affecting potential growth and cause seedling death (BAUERLE et al., 2002; MONTAGUE; KJELGREN, 2006).

The amount of water available for nursery irrigation is forecasted to decline over the next decade. Along with declining availability, the cost of water for irrigation is predicted to increase substantially for most nurseries. Limited availability, higher direct costs, and irrigation runoff issues are projected to compel the container nursery industry to adopt procedures and technology that will increase irrigation water use efficiency (BEESON JR et al., 2004).

In this study we examined if the irrigation depths (8, 11 e 14 mm), splitted in two frequencies, affect the seedling quality of *Calophyllum brasiliense* Cambess. (Guanandi) at nursery and initial development after planting in pot.

4 MATERIAL AND METHODS

4.1 Nursery phase

The experiment was conducted from October 2011 to October 2012 in a nursery located in Botucatu, São Paulo State, Brazil (22º1'S, 48º25'O). The climate of the region is Cwa according to the Köppen climate classification.

The *Calophyllum brasiliense* Cambess. seeds were collected in June 2011 on forest fragment located in Botucatu, Brazil and stored for 110 days at a temperature of 10°C ± 2°C and a relative humidity between 8 and 12%, when they were sowing in plastic tubes (92 cm³). The plastic tubes were placed in polypropylene trays and filled with a substrate consisting of *Sphagnum* peat, vermiculite and carbonized rice chaff (2:1:1; volume basis).

The properties porosity and water retention of substrate were analyzed according to Guerrini and Trigueiro (2004), and pH and electrical conductivity were analyzed according to Brazil (2007) (Table 1).

Table 1. Properties of substrate used in this experiment.

Porosity (%)			Water retention (mL per plastic tube)	Electrical conductivity (mS cm^{-1})	pH
Macro	Micro	Total			
24.2	59.3	83.4	54.6	0.5	6.5

The soluble fertilizers Yoorin® Master 1S and Fosmag® 500B and the controlled release fertilizer Osmocote® with NPK (19:6:10) were added to the substrate according to described by Silva and Silva (2015a).

Sowing was performed manually by placing a seed in each plastic tube. The trays were transferred to an automated greenhouse with relative humidity control (greater than 80%), maintained through nebulization with a 7 L h^{-1} flow nozzle, triggered automatically by an electric panel for 10 seconds, every 15 minutes, from 9:00 am to 4:00 pm. The seedlings remained in this environment for 14 days. After, the seedlings were transferred to a shade house (with 50% light reduction) and irrigated with micro-sprinklers with a 200 L h^{-1} flow nozzle, triggered automatically by an electric panel for 20 seconds, every 30 minutes, from 9:00 am to 4:00 pm for 42 days.

In this phase, the experiment was conducted using a completely randomized design with a factorial scheme that consisted of three daily irrigation depths (8, 11 and 14 mm), splitted into two irrigation frequencies (two and four times a day) applied by micro-sprinklers triggered automatically by electric panel (Table 2).

Table 2. Composition of the treatments used in the experiment[(1)].

Treatments	Compositions
ID8F2	4 mm 10:00 am and 4 mm 2:00 pm
ID8F4	2 mm 9:00 am, 2 mm 11:00 am, 2 mm 1:00 pm and 2 mm 3:00 pm
ID11F2	5.5 mm 10:00 am and 5.5 mm 2:00 pm
ID11F4	2.75 mm 9:00 am 2.75 mm 11:00 am, 2.75 mm 1:00 pm and 2.75 mm 3:00 pm
ID14F2	7 mm 10:00 am and 7 mm 2:00 pm
ID14F4	3.5 mm 9:00 am, 3.5 mm 11:00 am, 3.5 mm 1:00 pm and 3.5 mm 3:00 pm

[(1)]ID - irrigation depths (mm) and F - irrigation frequencies (times a day).

Each treatment consisted of 4 repetitions (trays). In each tray, the percentage occupancy of the seedlings was 25%. In each repetition, the 12 central seedlings were the useful seedlings, and the 18 other surrounding constituted the boundary, totaling 48 useful seedlings per treatment.

Before starting the treatments, were selected seedlings to homogenize the repetitions, ensuring that height and stem diameter averages did not statistically differ ($p < 0.05$). The mean values and standard deviations of these variables were 12.0 cm ± 1.3 and 2.32 mm ± 0.26, respectively.

To begin the treatments, the repetitions were distributed in six outdoor beds, covered with a plastic light diffuser, in the sunlit area at nursery.

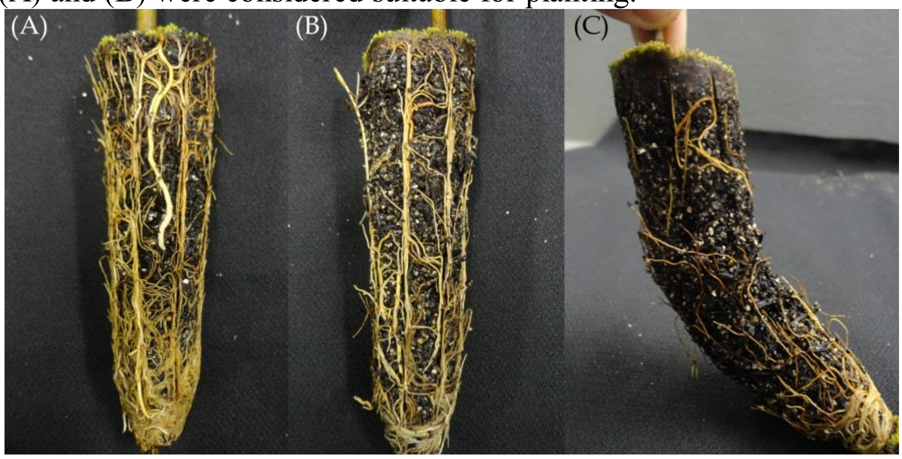
The side dressing fertilization was performed twice a week for 85 days after the start of the treatment application. In each fertilization, the 4 mm irrigation depth of nutrient solution was applied via fertigation in all treatments. The solution comprised the fertilizers according to described by Silva and Silva (2015a). The hardening fertilization was performed twice a week from 85 until 120 days after the beginning of treatments. In each fertilization, the 4 mm irrigation depth of nutrient solution was applied via fertigation in all treatments. The fertilizer solution was composed according to described by Silva and Silva (2015a).

To evaluate the seedlings quality, the following morphological variables were measured 120 days after the start of treatments: height (cm), measured using a millimeter ruler, from the base of the stem to the apical bud and stem diameter (mm) measured using a precision caliper (these two variables were evaluated in the 12 useful seedlings per repetition) as well as shoot, root and total dry mass (g) of the segment of the cuttings that was closest to the substrate. To determine the root dry mass, the roots were washed on a sieve using tap water. The roots and shoots were subsequently dried to a constant mass in an oven at 70 °C and then weighed with a high-precision electronic scale. The roots and shoots measurement was conducted on 6 useful seedlings per repetition. From the combination of morphological variables, the total dry mass (g) and the Dickson quality index was determined using the following equation (1):

$$DQI = \frac{\text{Total dry mass (g)}}{\left(\frac{\text{Height (cm)}}{\text{Stem diameter (mm)}}\right) + \left(\frac{\text{Shoot dry mass (g)}}{\text{Root dry mass (g)}}\right)} \quad (1)$$

The root system quality was evaluated according to Silva et al. (2013), in the same seedlings. This variable had four categories: "optimum" indicating a well-structured root system with no flexibility and the presence of new roots (Figure 1A); "good" indicating root systems that had good structure but some flexibility which would require greater care in planting to avoid harming the field performance (Figure 1B); and "poor" indicating root systems that had no aggregated substrate or new roots and which were considered unfit for planting in the field (Figure 1C). Both "optimum" and "good" root systems were considered "suitable" for planting.

Figure 1. Quality categories assigned to the root systems of *Calophyllum brasiliense* seedlings: optimum (A), good (B) and poor (C). The seedlings with the concepts (A) and (B) were considered suitable for planting.



The irrigation application efficiency (IAE) of each treatment was assessed at 120 days after the start of the treatments in eight seedlings per treatment, and it is defined, according to

Israelsen (1950), as the correlation between the amount of water retained in the root zone and the total amount of water applied. To quantify the amount of water retained in the root zone, plastic bags were secured with elastic in the plastic tubes. The mass of the whole (plastic tube + seedling + plastic bag + elastic) was measured before and after irrigation in each treatment on an electronic precision scale. The total amount of water applied is the sum of water retained in the root zone + the water drained from the plastic tube after irrigation, captured by plastic bags stuck in the plastic tubes. This water drained was measured on an electronic precision scale.

An analysis of variance was performed to compare the effect of irrigation depths and irrigation frequency on variables analyzed at nursery phase. When the value of the F test indicated a significant effect, we used the Tukey's test ($p < 0.05$) to compare differences between means of treatments.

4.2 Initial development after planting phase

After end of nursery phase, the seedlings were kept in their treatments for more 20 days, when six seedlings from each treatment were planted in pots of 7 L, containing 8 kg of soil each. The soil was collected from the surface layer (0-20 cm), corresponding to a dystrophic Red Latosol, medium texture. The fertilizer NPK (4:14:8) in dosages 2 kg of fertilizer per cubic meter and limestone, in the same dose, were added to the soil and mixed for 5 minutes in a mixer. Before and immediately after planting, each pot was irrigated, respectively, with 2 and 1 L of water. The plants were kept in a completely randomized design in a greenhouse covered with transparent plastic for 120 days and irrigated with 0.5 L every nine days.

The plants were evaluated immediately after planting and thereafter at intervals of 30 days from the variables: height (cm), measured using a millimeter ruler, from the base of the stem to the apical bud, and stem diameter (mm) measured using a precision caliper. At 120 days after planting, shoot and root dry mass of plants (g) of the segment of the seedlings that was closest to the soil. To determine the root dry mass, the roots were washed on a sieve using tap water. The roots and shoots were subsequently dried to a constant mass in an oven at 70 °C and then weighed with a high-precision electronic scale.

In the statistical analysis of initial development after planting, when the value of the F test indicated a significant effect, we used regression analysis over time (height and stem diameter) and Tukey's test ($p < 0.05$) (shoot and root dry mass).

5 RESULTS AND DISCUSSION

5.1 Nursery phase results

The 11 and 14 mm irrigation depths splitted into two times a day formed seedlings with greater height and shoot and total dry mass compared to the same irrigation depths splitted into four times a day. For the root dry mass and Dickson quality index, this same irrigation depths splitted into two times a day did not differ from the splitted four times a day. In the stem diameter, only the 14 mm irrigation depth splitted into two times a day overcame the splitted four times a day (Table 3).

Table 3. Effects of the interaction between irrigation depths and frequencies on height, stem diameter, shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM) and Dickson quality index (DQI) in *Calophyllum brasiliense* seedlings 120 days after the beginning of treatments[(1)].

Irrigation depths (mm)	Height (cm)			Stem diameter (mm)		
	Frequencies			Frequencies		
	2x	4x	CV (%)	2x	4x	CV (%)
8	22.1Cb	26.7Aa	16.6	4.80Bb	5.30Ba	12.8
11	35.2Aa	26.9Ab	15	5.89Aa	5.61Aa	12.3
14	30.9Ba	26Ab	15	5.91Aa	5.65Ab	8.6
CV (%)	15.1	16		11.7	10.8	

Irrigation depths (mm)	SDM (g)			RDM (g)		
	Frequencies			Frequencies		
	2x	4x	CV (%)	2x	4x	CV (%)
8	2.91Cb	3.92Aa	16.4	1.44Bb	1.72Aa	18.9
11	5.27Aa	3.54Ab	20.4	1.81Aa	1.62Aa	20.5
14	4.52Ba	3.87Ab	16.2	1.76Aa	1.68Aa	17.3
CV (%)	19.5	16.2		19.6	18.3	

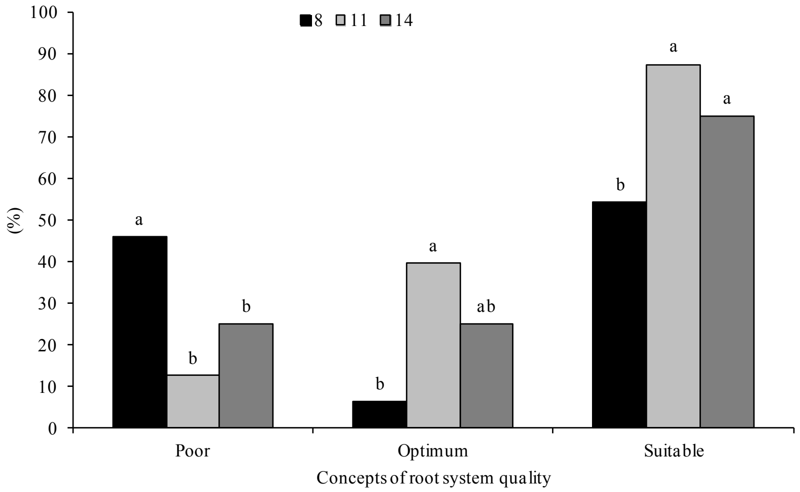
Irrigation depths (mm)	TDM (g)			DQI		
	Frequencies			Frequencies		
	2x	4x	CV (%)	2x	4x	CV (%)
8	4.35Cb	5.64Aa	15.8	0.67Bb	0.78Aa	20.3
11	7.07Aa	5.16Ab	19.5	0.82Aa	0.76Aa	24.6
14	6.28Ba	5.56Ab	15.1	0.81Aa	0.81Aa	19
CV (%)	18.4	15.6		22.8	17.5	

[(1)]Means followed by the same capital letter in the column and the same lowercase letter across the row are not significantly different according to the Tukey's test ($p < 0.05$).

In the irrigations splitted into two times a day, the 11 mm irrigation depth overcame the 8 mm irrigation depth in all morphological variables and compared to the 14 mm irrigation depth provided greater or equal development in all morphological variables of seedlings. This indicates that the seedlings irrigated with 8 mm irrigation depth showed this behavior because they were likely saturated just a few inches below the surface layer of the substrate, causing water deficits and the 14 mm irrigation depth was excessive, which may have led to the nutrient leaching. Similar results were found by Silva and Silva (2015a, 2015b) for species *Aspidosperma polyneuron* and *Piptadenia gonoacantha*, where the 11 mm irrigation depth produced the same morphological development of seedlings as the 14 mm irrigation depth. According to Thomas and Perry (1980) and Lea-Cox, Ross and Teffeau (2001), water is an integral component of the nutrient management equation, particularly when the irrigation volume exceeds the capacity of water retention of the substrate.

The 8 mm irrigation depth, although did not differ from the 14 mm irrigation depth on the category "optimum", produced a greater and smaller amount of seedlings with "poor" and "suitable" root systems, respectively, showing that the 8 mm irrigation depth is insufficient to produce seedlings with root system quality (Figure 2).

Figure 2. Effect of irrigation depths (mm) on the categories "poor", "optimum" and "suitable" of root system quality of *Calophyllum brasiliense* seedlings 120 days after the beginning of treatments. Means followed by the same letter in the same category are not significantly different according to the Tukey's test ($p < 0.05$); CV(%): Poor (1.6%), Optimum (1.7%) and Suitable (0.6%).



According to Taiz and Zeiger (2004), the proliferation of roots depends on the availability of water and nutrients in the microenvironment surrounding the root, called the rhizosphere. If the rhizosphere is nutrient-poor or too dry, root growth is slow.

The 11 mm irrigation depth, that did not differ the 14 mm irrigation depth, produced a smaller and greater amount of seedlings with "poor" and "suitable" root systems, respectively. This indicates that the 14 mm irrigation depth was excessive and unnecessary during the treatment application. The largest plant growth is not always associated with the highest rates of irrigation (FOX; MONTAGUE, 2009). Water excess can promote leaching of nutrients and a favorable microclimate for the development of diseases, besides the environmental issues related to water saving and accumulation of leachate in the soil (LOPES et al., 2005).

The increased of irrigation depths in the irrigations splitted into four times a day reduced the irrigation application efficiency (IAE). In irrigations splitted into two times a day, the 11 and 14 mm irrigation depths did not differ in this variable (Table 4).

Table 4. Effects of the interaction between irrigation depths and frequencies on irrigation application efficiency (IAE) in *Calophyllum brasiliense* seedlings 120 days after the beginning of treatments[1].

Irrigation depths (mm)	**IAE (%)**		
	Frequencies		
	2x	4x	CV (%)
8	63.8Aa	66.1Aa	6.6
11	60.2Ba	62.0Ba	8.2
14	59.2Ba	54.8Cb	4.7
CV (%)	6.4	6.8	

[1]Means followed by the same capital letter in the column and the same lowercase letter across the row are not significantly different according to the Tukey's test ($p < 0.05$).

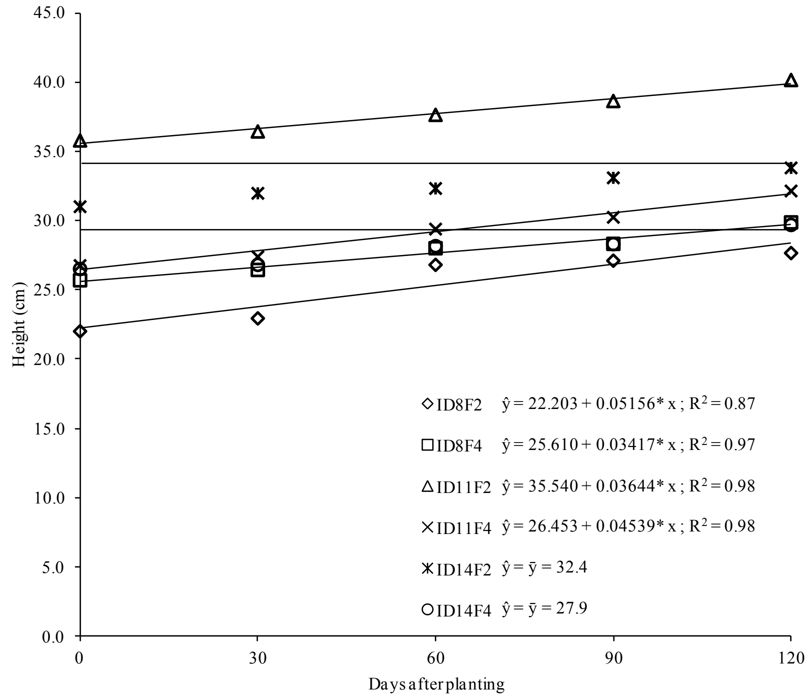
In the irrigations splitted into two times a day, the same IAE of 11 and 14 mm irrigation depths was possible because the seedlings produced in the 14 mm irrigation depth had less amount of shoot (height and shoot dry mass), reducing water capitation and consequently reducing runoff. According to Lea-Cox, Ross and Teffeau (2001) and Million, Yeager and Albano (2007), the size of the seedlings and the capitation of water is an important factor that may influence the IAE. In the irrigations splitted into four times a day, all irrigation depths applied formed seedlings with same amount of shoot (equal capacity of water capitation), thus the IAE reduction was due to increased of irrigation depths. This result is according to Silva and Silva (2015b), where IAE was related to the shoot development in *Aspidosperma polyneuron* seedlings.

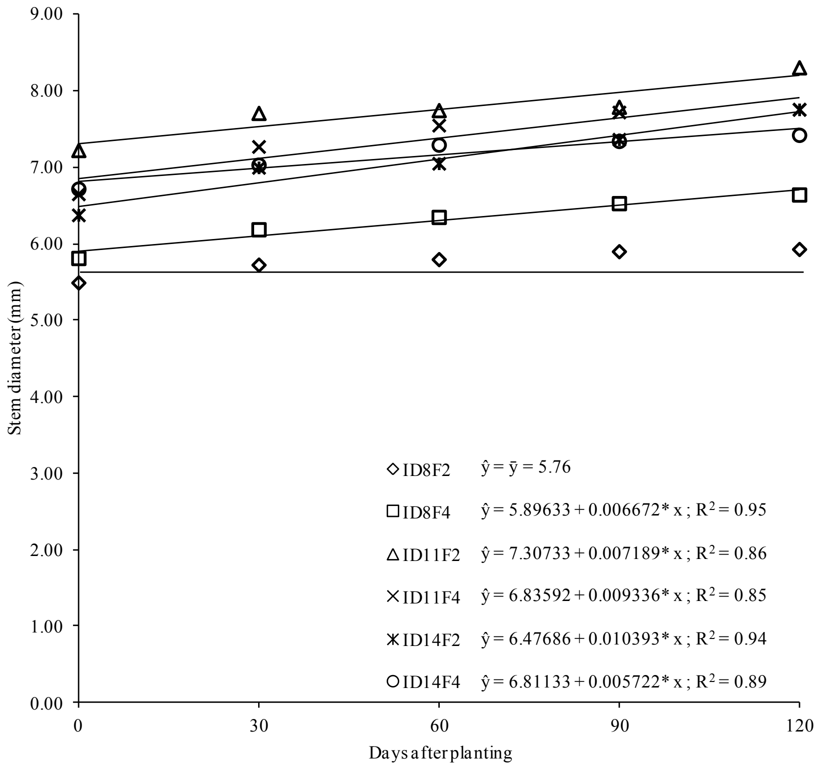
The 8 mm irrigation depth splitted into two times a day increased the IAE. This may happen because likely was saturated just a few inches below the surface layer of the substrate. The key to increased IAE is in control the application rate, application duration, and interval between applications. If low water volumes are used without taking into account the maintenance of adequate water in the container, stomatal closure may occur, reducing photosynthesis and consequently reducing plant growth (WARREN; BILDERBACK, 2005).

5.2 Initial development results after planting phase

The effect of all treatments applied in the seedlings at nursery phase on height and stem diameter during 120 days after planting in pot showed linear behavior, with the exception of 14 mm irrigation depth applied in both frequencies (height) and 8 mm irrigation depth splitted into two times a day (stem diameter), which showed no significant effects (Figure 3).

Figure 3. Effects of irrigation depths (ID) and frequencies (F) applied in the *Calophyllum brasiliense* seedlings at nursery phase on the height and stem diameter during 120 days after planting in pot. *Significant according to the F test ($p < 0.05$).





The 11 mm irrigation depth splitted into two times a day, which formed greater seedlings at nursery phase, continued providing greater heights and stem diameters after planting in pot, showing the influence of seedlings quality in the initial development and the possibility of saving water in irrigation of this species at nursery. This result is in accordance with the finding to Silva and Silva (2015a) that worked with water management in *Piptadenia gonoacantha*, other native species of Brazilian Atlantic forest.

The 14 mm irrigation depth, in both irrigation frequencies, though it had good results at end of nursery phase, suffered the “transplant shock” and stagnated the height growth. Transplant shock is the term used to describe the reduced growth of seedlings caused by acclimatization to new environmental conditions immediately following planting out (DAVIS; JACOBS, 2005).

The 8 mm irrigation depth splitted into two times a day, which formed smaller seedlings at nursery phase, continued providing smaller heights and stem diameters after planting in pot, showing the influence of seedlings quality in the initial development.

In root and shoot dry mass variables, the 11 mm irrigation depth splitted into two times a day at nursery resulted in greater growth after planting in pot compared to the same irrigation depth splitted into four times a day (Table 5).

Table 5. Effects of the interaction between irrigation depths and frequencies applied in *Calophyllum brasiliense* seedlings at nursery phase on the shoot dry mass (SDM) and root dry mass (RDM) at 120 days after the planting in pot[(1)].

Irrigation depths (mm)	SDM (g)			RDM (g)		
	Frequencies			Frequencies		
	2x	4x	CV (%)	2x	4x	CV (%)
8	3.28Ba	4.49Aa	25.9	1.58Bb	2.53Aa	14.9
11	9.10Aa	4.94Ab	14.7	3.84Aa	2.62Ab	12.6
14	5.56Ba	5.31Aa	15.9	3.04ABa	3.45Aa	25.6
CV (%)	17.5	18.5		24.8	13.2	

[(1)]Means followed by the same capital letter in the column and the same lowercase letter across the row in the same variable are not significantly different according to the Tukey’s test ($p < 0.05$).

After planting in pot, the shoot and root dry mass of seedlings produced in the 14 mm irrigation depth did not differ with respect irrigation frequency. Furthermore, there was no difference between the irrigation depths splitted into four times a day.

The 11 mm irrigation depth splitted into two times a day overcame the others irrigation depths in shoot dry mass. Furthermore, this treatment was greater and equal to the 8 and 14 mm irrigation depths, respectively, in root dry mass. Seedling quality depends on the ability to produce new roots quickly, the speed with which seedlings get anchored into the ground and then start assimilating and growing after planting out, a well-developed root system, sun-adapted foliage, a large root collar diameter, a balanced shoot/root ratio, good carbohydrate reserves, and optimum mineral nutrition content (MAÑAS; CASTRO; DE LAS HERAS, 2009).

6 CONCLUSIONS

1. For *Calophyllum brasiliense* seedlings, irrigation efficiency is related to shoot development and irrigation depths applied.

2. Increases in irrigation efficiency do not necessarily produce greater morphological development and root system quality of seedlings at nursery phase.

3. The 11 mm irrigation depth produces the same amount of seedlings with suitable root systems for planting as the 14 mm irrigation depth, using 21% less water.

4. The application of 11 mm irrigation depth splitted in two times a day, compared to 14 mm irrigation depth, produces higher or equal morphological development in *Calophyllum brasiliense* seedlings, which continues after planting.

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