

Water use in the growth of atlantic forest tree species seedlings under different shading levels

Uso de água no crescimento de mudas de espécies arbóreas da mata atlântica sob diferentes níveis de sombreamento

Mateus Marques Bueno^{1*}, Paulo Sérgio Santos Leles², Marinaldo Ferreira Pinto³,
Alexander Silva de Resende⁴, Beatriz Rodrigues Monteiro Couto³, Daniel Fonseca de Carvalho³

¹Instituto Federal de Educação, Ciência e Tecnologia de Minas Gerais/IFMG, São João Evangelista, MG, Brasil

²Universidade Federal Rural do Rio de Janeiro/UFRRJ, Departamento de Silvicultura, Instituto de Florestas, Seropédica, RJ, Brasil

³Universidade Federal Rural do Rio de Janeiro/UFRRJ, Departamento de Engenharia, Instituto de Tecnologia, Seropédica, RJ, Brasil

⁴Empresa Brasileira de Pesquisa Agropecuária/Embrapa, Embrapa Agrobiologia, Seropédica, RJ, Brasil

*Corresponding author: mateus.bueno@ifmg.edu.br

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ABSTRACT

The increase in the demand for seedlings of native tree species makes it important to determine their water and light requirements, which are important factors in their production, in terms of costs and time. Water use and productivity in the growth of seedlings of *Dalbergia nigra* (Vell.) Allemão ex Benth., *Apuleia leiocarpa* (Vogel) J.F. Macbr and *Hymenaea courbaril* L. were determined under four light levels (three shading levels and control), using a randomized block design with four replicates. Height, stem diameter, leaf area and biomass, as well as Dickson quality index (DQI) were evaluated. The seedlings were transplanted into 280-cm³ plugs, filled with substrate composed of pure biosolids, and irrigated by a drip system with automatic management. The highest total volumes applied were 3.1 L per *D. nigra* seedling (in 37 and 58% shading), 2.5 L per *A. leiocarpa* seedling (in 37% shading) and 3.8 L per *H. courbaril* seedling (in full sun). Growth indices, confirmed by the DQI, indicate that shading levels of 37 and 58% for *D. nigra*, 37% for *A. leiocarpa*, and full sun for *H. courbaril* are the most recommended. The highest volumes of irrigation promoted the greatest development of the species, in general for intermediate shading, which provided the highest values of DQI and irrigation water productivity.

Index terms: Automatic irrigation management; biosolid; Jacarandá-da-Bahia; Garapa; Jatobá.

RESUMO

O aumento da demanda por mudas de espécies arbóreas nativas torna importante a determinação de suas necessidades hídricas e de luminosidade, que são fatores importantes na otimização dos custos e do tempo de produção. O uso e a produtividade da água no crescimento de mudas de *Dalbergia nigra* (Vell.) Allemão ex Benth., *Apuleia leiocarpa* (Vogel) J.F. Macbr e *Hymenaea courbaril* L. foram determinados em quatro níveis de luminosidade (três níveis de sombreamento e controle), utilizando delineamento em blocos casualizados, com quatro repetições. A altura, o diâmetro do coleto, a área foliar e a biomassa foram avaliadas, assim como o índice de qualidade de Dickson (IQD). As mudas foram transplantadas em tubetes de 280 cm³, preenchidos com biossólido puro, e irrigadas por gotejamento com manejo automático. Os maiores volumes totais aplicados 3,1 L por muda de *D. nigra* (com 37 e 58% de sombreamento), 2,5 L por muda de *A. leiocarpa* (37% de sombreamento) e 3,8 L por muda de *H. courbaril* (a pleno sol). Os índices de crescimento, confirmados pelo IQD, indicam que os sombreamentos de 37 e 58 % para *D. nigra*, 37 % para *A. leiocarpa* e a pleno sol para *H. courbaril* são os mais recomendados. Os maiores volumes de irrigação promoveram maior desenvolvimento das espécies, em geral com sombreamento intermediário, os quais proporcionaram os maiores valores de IQD e produtividade da água de irrigação.

Termos para indexação: Manejo automático de irrigação; biossólido; Jacarandá-da-Bahia; Garapa; Jatobá.

INTRODUCTION

The production of seedlings of native tree species is necessary due to the increased demand for environmental restoration projects (Scalon et al., 2011), mainly in the Atlantic Forest, currently with 12.5% of its original coverage and is considered one of the most threatened

biomes in the world (Santos et al., 2019). In addition, in reforestation process many species are cultivated for economic purposes (Delgado et al., 2017), and success in planting depends on seedling quality, which is influenced by water supply, local microclimate (Keffer et al., 2019), substrate used and management (Davide et al., 2015).

In tree species nurseries there is usually no irrigation management and, therefore, losses of up to 70% of the applied water have already been observed (Dumroese et al., 2005). Thus, determining the water requirements of the species makes it possible to adjust the operation of the irrigation system in the nurseries, generating savings of water and nutrients, ensuring an effective production of seedlings. In addition to water, the growth of forest seedlings in nurseries, especially of species used in forest restoration, is directly influenced by factors such as temperature, relative humidity and luminosity (Reis et al., 2016). Species considered shade tolerant are able to survive for long periods under the canopy because they can develop adaptations in the photosynthesis process, while plants that show escape mechanism tend to maximize light interception by adapting their growth and occupying gaps in the canopy (César et al., 2014).

Availability of nutrients in the substrate also affects the development of seedlings. Thus, the substrate should provide adequate conditions for germination and initial growth of seedlings, with good physical and chemical characteristics (Dantas et al., 2009). In this context, biosolids, obtained from sewage sludge stabilization, are an alternative for seedling production (Abreu et al., 2017) and its use can minimize the occurrence of environmental problems (Caldeira et al., 2013), due to the need for an appropriate final destination for this waste (Alleoni; Fernandes; Correia, 2012).

Among the forest tree species used in forest restoration, *Dalbergia nigra* (Vell.) Allemão ex Benth, *Apuleia leiocarpa* (Vogel) J.F. Macbr and *Hymenaea courbaril* L. are classified as of secondary growth and occur throughout Brazil (Lorenzi, 2014). Popularly known as jacarandá-da-bahia, *D. nigra* is used in the manufacture of furniture and musical instruments, as well as construction and recovery of degraded areas (Costa et al., 2015). Due to its natural durability, the high market value has contributed to its inadequate exploitation (Ataíde et al., 2016), putting it under high risk of extinction (Gasson et al., 2010). *A. leiocarpa* has abundant regeneration in secondary forests and, according to Carvalho (2003), tolerates shading between 50 and 70%. Its wood is sturdy and widely used in the construction of external structures. *H. courbaril* has the ability to develop in environments with different edaphoclimatic characteristics (Nascimento et al., 2011). It is intensively exploited due to its size (height and stem diameter) and the good physical characteristics of its wood (Lacerda; Kanshiro; Sebbenn, 2008), being widely used in civil construction and in furniture industry (Tiago et al., 2018).

These species are commonly produced in forest nurseries, usually without management of irrigation systems.

Therefore, considering the hypothesis that the adequate amount of water and luminosity can contribute to optimizing the growth of forest seedlings, we evaluated the water use and productivity in the growth of seedlings of three tree species of occurrence in the Atlantic Forest, subjected to shading levels and automated irrigation management.

MATERIAL AND METHODS

Three experiments were conducted from July to December 2019 in an experimental area of the UFRRJ campus, in the municipality of Seropédica, State of Rio de Janeiro, Brazil (22°46'29.55" S and 43°41'12.16" W). The regional climate is Aw type according to Köppen's climate classification, with annual averages of precipitation and temperature ranging from 1,300 to 1,600 mm and from 22 to 24° C, respectively (Alvares et al., 2013).

Seedlings of the tree species *Dalbergia nigra* (Jacarandá-da-Bahia), *Apuleia leiocarpa* (Garapa) and *Hymenaea courbaril* (Jatobá) were evaluated under four light levels – three shading levels and control (full sun), in a randomized block design with four replicates. The seeds came from parent trees of the Atlantic Forest of Rio de Janeiro and, after a period of about 20 days in sand boxes for germination, measurements were taken and seedlings with height (cm) and diameter (mm) values close to the averages were selected and transplanted to 280-cm³ plugs on plastic trays and placed on 16 metal workbenches with dimensions of 0.8 x 1.2 x 1.5 m. On each workbench, there was a tray for each species, whose number of plugs was 8 (*D. nigra*), 10 (*A. leiocarpa*) and 6 (*H. courbaril*), according to the availability of homogeneous seedlings.

The plugs were filled with pure biosolids (sewage sludge), obtained from the Rio de Janeiro State Water and Sewage Company (CEDAE), which are rich in nutrients and organic matter (Abreu et al., 2017) and have adequate physical and chemical qualities for the production of seedlings of native tree species, especially in 280-cm³ plugs (Sousa et al., 2019). Analysis of total nutrients showed 1.61% N, 0.68% P, 0.27% K and 9.66% organic carbon. The physical-hydraulic parameters of the substrate were obtained through the simplified evaporation method (Schindler; Müller, 2006), operated by the commercial device Hyprop® (Pertassek; Peters; Durner, 2015). The average particle density (PD) was 1.71 g cm⁻³ and the bulk density (BD) was 0.74 g cm⁻³, compatible with the physical characteristics of humic soils (PD lower than 2.65 g cm⁻³ and BD from 0.75 to 1.0 g cm⁻³). Approximately 70% of the average particle diameter is between 1.0 and 0.5 mm, indicating that the substrate has a high value of specific surface area.

The workbenches were covered on top and sides by commercial polyolefin agricultural nets in black color (sombrite), with nominal shading of 35, 50 and 80%, except the workbenches that remained under full sun. In order to better characterize the treatments, the illuminance of the nets (I) was evaluated for six days, at one-hour intervals, using a digital luxmeter (LD-400 model, Instrutherm), as well as global solar radiation (GSR) and photosynthetically active radiation (PAR), respectively using a pyranometer (MP-200 model, Apogee) and a Quantum meter (MQ-200 model, Apogee). The average values of daily illuminance were 74.238, 46.395, 31.620 and 5.813 Lux, respectively characterizing the treatments as 0 (full sun) (C), 37 (S1), 58 (S2) and 92% (S3) of shading level. The average GSR and PAR values were 597.0, 336, 191 and 61 W m⁻², and 946, 528, 345 and 91 mol m⁻² d⁻¹ for C, S1, S2 and S3, respectively.

A drip irrigation system with automatic water application, composed of polyethylene laterals (16 mm) with one dripper per tube (PCJ model - Netafim), nominal flow rate of 1.20 L h⁻¹, was installed for each species and shading level (Figure 1). After performing flow tests, the system had distribution uniformity greater than 95%. The irrigation system was pressurized by 3 direct current pumps (22-2361 model, Shurflo, 12 VDC), responsible for the irrigation of each species individually. The electrical supply was provided by two photovoltaic modules (YL140p-17b model, Yingu Solar, 140 W and 22.3 V) and 3 batteries, connected in series. The volume of water applied was measured by an electronic control system (Figure 1).

Irrigation management was performed through the simplified irrigation controller (SIC) (Medici et al., 2010), which operates in response to soil/substrate water tension and is regulated by the level difference between a porous cup (sensor) and a pressure switch. Twelve independent actuators were used, one for each treatment, whose sensors were made from a commercial filter candle, generating ceramic micro-cups.

The sensors were installed vertically in the substrate at 5 cm depth, with a height difference of 40 cm in relation to the pressure switch, responsible for regulating the activation of each of the irrigation systems. When the water tension in the substrate reached approximately 4.0 kPa, the pressure switch allowed the passage of electric current, activating the pump and the corresponding solenoid valve, which allowed the passage of water through the central tube.

For monitoring the moment and time of irrigation in each treatment, an electronic data collection and storage system was installed (Figure 1), composed of an Arduino Mega board programmed to perform readings every second,

SD card and voltage dividers installed in each treatment, so that when the irrigation actuator started an irrigation a high level was generated at the analog port of the controller, indicating the beginning and end of irrigation.

In order to avoid water losses by percolation in the plugs, the electronic data collection and storage system was programmed to interrupt the power supply to the irrigation systems for one minute, every minute of irrigation. If the energy supply of the pressure switch continued to be active, the irrigation system was activated again. This procedure was repeated until the pressure switch was turned off by the automatic irrigation system, in response to the increase in water tension in the substrate.

Weather monitoring in the full sun condition was carried out from the data of INMET station (Ecologia Agrícola - A601), installed in the municipality of Seropédica, which provides information every hour. With the meteorological data, the reference evapotranspiration (ET_o) was estimated daily by the Penman-Monteith FAO-56 method (Allen et al., 1998). To determine the relative humidity and temperature, digital thermo-hygrometers (HT-4010 model, Icel) were installed inside the environments created on the workbenches with different shading levels and programmed to store data every 30 minutes. For each treatment, the vapor pressure deficit (VPD) was calculated according to Allen et al. (1998).

The variables seedling height (H) and stem diameter (D) were measured every 30 days in all seedlings of all treatments. At the end of the experimental period, readings of total leaf area (LA, in cm²) were taken with a leaf area meter (LI-3100C) and the total dry mass (TDM) (biomass) was determined, obtaining the dry mass of shoots (SDM, in g) and root system (RDM, in g). For dry mass determination analyses, three seedlings per treatment were collected, separated into shoots and root system, placed in paper bags, and dried in an oven at 65 °C until reaching constant weight.

The *D. nigra* and *H. courbaril* seedlings were collected at 110 and 140 days after emergence (DAE), respectively, when they had shoot height and stem diameter according to the standards required to be taken for field planting. Davide et al. (2015) and Souza Junior and Brancalion (2016) reported that seedlings acquire a commercial standard and are ready to be taken to the field when they reach heights of 30.0, 20.0 and 20.0 cm and stem diameters of 3.0, 2.5 and 5.0 mm, respectively, for *D. nigra*, *A. leiocarpa* and *H. courbaril*. For *A. leiocarpa*, the experiment was ended at 140 DAE, when the seedlings had, on average, height of 17.2 cm and stem diameter of 2.3 mm. According to Gomes et al. (2008), this species has slow to moderate growth.

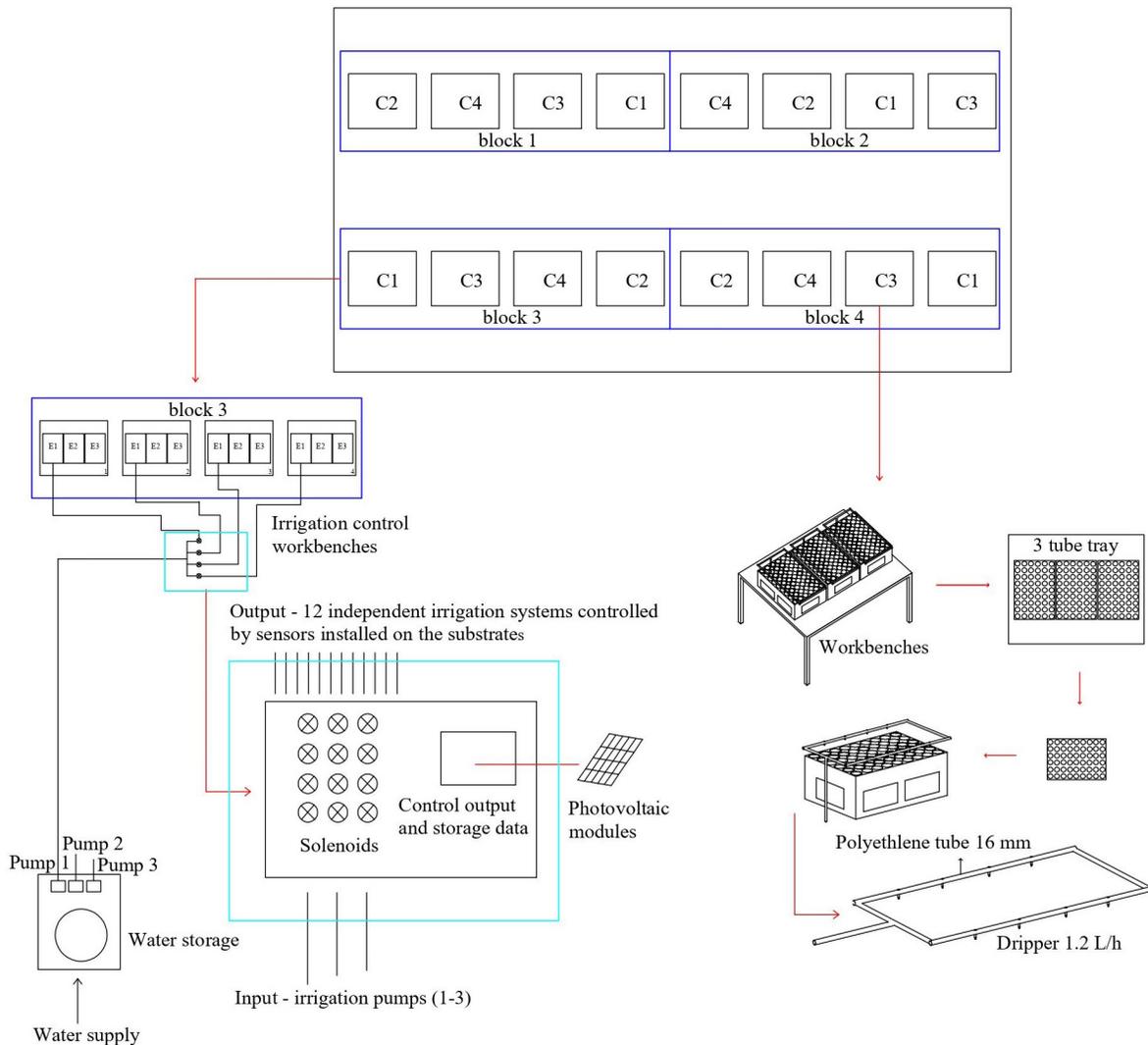


Figure 1: Experimental scheme (without scale) with details and distribution of the benches, and support units (water supply and storage system and irrigation control).

From the collected data, the relation between height and stem diameter (Davide et al., 2015), also commonly known as H/D (slenderness), and the Dickson quality index (DQI) (Dickson; Leaf; Hosner, 1960) (Equation 1) were calculated.

$$IQD = \frac{TDM}{\frac{H}{D} + \frac{SDM}{RDM}} \quad (1)$$

where TDM is total dry mass (g), H is height (cm), D is diameter (mm), SDM is dry mass of shoots (g), and RDM is root system mass (g). According to Eloy et al. (2013), the

DQI is an integrated morphological measure and considered as a good indicator of seedling quality, considering the robustness and balance of the phytomass distribution. It can vary depending on the species, the management of seedlings in the nursery, the type and proportion of the substrate, the volume of the container and, mainly, according to the age at which the seedling was evaluated (Gomes et al., 2013). Therefore, there is no fixed range of values for this index, but a higher DQI means better quality of the seedling produced (Caldeira et al., 2012).

Irrigation water productivity (W_{Pi}) was calculated by Equation 2, using the SDM, RDM and TDM as yield (Y), in relation to the volume of water applied by irrigation (V_w).

$$WP_i = \frac{Y}{V_w} \quad (2)$$

where Y is productivity (total, shoots, or root systems dry mass – g), and V_w is total volume of irrigation (L).

The analysis of variance (ANOVA) was performed and for that the normality and homogeneity of the residuals were verified by the Shapiro-Wilk and Bartlett tests, respectively, at 5% probability. When significant, using the F test at 5% probability, regression analysis was performed using the Student's t test to verify the fit of the linear and quadratic models to the biometric data, in response to the levels of shading. For choosing the model, the one with the lowest level of significance (p-value) and highest determination coefficient was considered. For cases in which the same regression model was selected, depending on the treatments, the Graybill (2000) identity test was applied, at the level of 5% probability, using the F test. When the models were considered identical, a single equation was generated to represent these models. For irrigation water productivity the Tukey test, at the level of 5% probability, was performed to shading level and species. All analyzes were performed with the aid of the computer programs R (3.6.0) and Sisvar (5.6).

RESULTS AND DISCUSSION

Meteorological aspects and volume applied by irrigation

There was a small variation in maximum and minimum temperatures between treatments, with the

highest average daily temperature (25.5 °C) detected in the S1 treatment (37% attenuation). Such higher temperature compared to the C treatment is possibly a result of the combination between the amount of radiation retained and wind attenuation in the microenvironment formed in the environment covered by the net (Monteiro et al., 2016), which may interfere with the daily temperature amplitude. The maximum temperature recorded in the period under the full sun condition was 43.8 °C, on 2019/11/05, while the minimum temperature was 12.0 °C, on 2020/08/16. The maximum amplitude recorded was 26.2 °C, on 2019/09/12.

The average relative humidity (RH) was approximately 80%, with lower increment in treatments with greater shading. Thus, the RH may have acted to maintain higher temperatures under covers with intermediate shading level. According to Santos et al. (2013), the water vapor attenuates radiation, so that when the RH is higher, the differences between night and daytime temperatures are smaller.

The average solar radiation in the experimental period was 15.8 MJ m⁻² day⁻¹, with a maximum value of 29.1 MJ m⁻² day⁻¹ on 09/27, and minimum of 3.6 MJ m⁻² day⁻¹, on 08/23. Accumulated reference evapotranspiration (ETo Ac) was 436.5 mm, with a maximum value of 7.7 mm day⁻¹ on 11/03. Although almost half of the experiment occurred in the winter period, there were 54 days of rain, with accumulated precipitation (Ppt Ac) of 280.2 mm (Figure 2). The average accumulated precipitations during the experiment in the different covers (S1, S2 and S3) were, respectively, 263.4, 235.6 and 190.5 mm, which influenced the amount of water applied in irrigation.

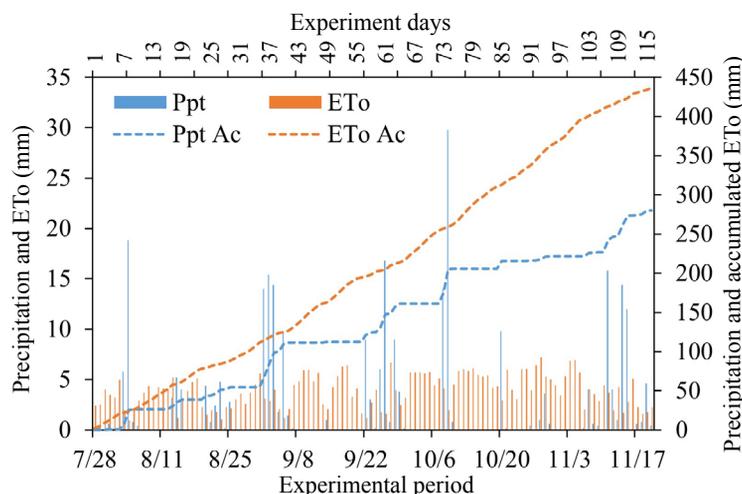


Figure 2: Outdoor precipitation (Ppt) and reference evapotranspiration (ETo) in the period from 07/28/2019 to 11/20/2019.

Of the 116 days of evaluation, precipitation was higher than ETo in just 27 days and higher than average ETo (3.8 mm day⁻¹) in 24 days. The highest weekly precipitation was 43.0 mm (09/02 to 08 - week 6), 39.60 mm (09/23 to 29 - week 9) and 44.60 mm (10/07 to 13 - week 11), when the minimum relative humidity was 54%, with average VPD values of 0.837, 0.779, 0.787 and 0.777 kPa, in the treatments C1, C2, C3 and C4, respectively. For ETo, the highest weekly depths were 31.3 mm (09/09 to 15 - week 7), 35.9 mm (09/30 to 10/06 - week 10) and 38.4 mm (10/28 to 11/03 - week 14), when precipitations totaled only 1.0, 0.2 and 5.2 mm, respectively. In these periods, the minimum relative humidity reached 38% and the average VPD values were 1.835, 1.771, 1.750 and 1.685 kPa, in treatments C1, C2, C3 and C4, respectively. In these weeks, the average volumes applied by the irrigation system were, respectively, 259.7, 244.1 and 591.2 mL per seedling of *D. nigra*, 257.2, 171.3 and 398.9 mL per seedling of *A. leiocarpa* and 287.0, 234.0 and 498.1 mL per seedling of *H. courbaril* (Figure 3).

The volume of water applied to seedlings under full sun and in shaded environments varied along the weeks of growth (Figure 3). It was expected that in full sun conditions the volume applied would always be greater than in shading treatments, but as the water requirement also depends on the growth rate of the seedlings, this consumption varied over time, differently for each species. Seedlings of *D. nigra* under intermediate shading levels (37 and 58%) exceeded the water consumption of those in the full sun treatment from the 10th week on, with total consumption of about 5% greater, whereas seedlings in the treatment with 92% shading always required around 30% less water (Figure 3A).

Seedlings of *A. leiocarpa* also showed variable consumption between treatments (Figure 3B), and the treatments with intermediate shading exceeded the requirement of the full sun condition from the eighth week and the requirement of the treatment with 92% shading from the 13th week. Unlike other species, *H. courbaril* seedlings used more water under full sun conditions (Figure 3C), in almost the entire period. For the treatments with intermediate shading, water consumption tended to become equal from the 10th week on, but the final consumption was approximately 17, 22 and 52% lower than that under full sun, respectively, for 37, 58 and 92% shading.

In response to atmospheric demand and characteristics of each species, the average total water volumes applied were 2.807, 2.141 and 2.860 L per seedling, respectively, for *D. nigra*, *A. leiocarpa* and *H.*

courbaril, and the irrigation systems were actuated, on average, 49, 49 and 51 times, for 2.8, 2.9 and 2.7 min, respectively (Table 1). This lower water consumption of *A. leiocarpa* seedlings probably occurred because the species has higher occurrence in drier soils (Carvalho, 2003). The highest volumes were applied in the treatment with 37% shading, for seedlings of *D. nigra* and *A. leiocarpa*, and under full sun, for seedlings of *H. courbaril*.

According to Monteiro et al. (2016), in general, the water requirement for forest seedlings decreases when the interception of solar radiation increases, but the volume of water required is also related to seedling growth. Therefore, it is necessary to understand the growth of the species to better understand these variations in consumption, as evidenced in the present study.

Growth and quality of tree seedlings

Except for the full sun treatment, for height, seedlings of *D. nigra* showed variation in height and stem diameter over the time after emergence, following a second-order polynomial trend (Figures 4A, B). With shading, the seedlings were able to reach the minimum standard of shoot height to be taken to the field (25 cm) at 95 DAE. Regarding stem diameter (D), seedlings from treatments under full sun and with cover of 37 (S1) and 58% (S2) showed standard to be taken to the field (D > 2.5 mm) with about 90 DAE. Under greater shading, the seedlings did not reach the standard stem diameter during the experimental period. This information indicates that, with shading within the range from 37 to 58%, it is possible to produce quality seedlings and, in less time, than under full sun and 92% shading, maximizing the use of the nursery, but using a greater amount of water (Table 1).

Regardless of the treatment, *A. leiocarpa* showed linear variation in shoot height (Figure 4C) and stem diameter (Figure 4D) as a function of production time. The commercial standard of height was reached with approximately 135 days after emergence for seedlings with 58 and 92% shading.

For the other treatments, the seedlings reached 20.0 cm in height with 221 and 160 DAE, respectively, for full sun (C) and 37% (S1) shading conditions, according to the fitted models. Regarding stem diameter, the seedlings reached 2.5 mm (standard) only in the C, S1 and S2 treatments (141 days) (Figure 4D). These results indicate that there were problems with the production of *A. leiocarpa* and that 58% shading level (S2) is the most indicated for the production of seedlings of this species, due to the lower volume of water when compared to 37% shading (S1) (Table 1).

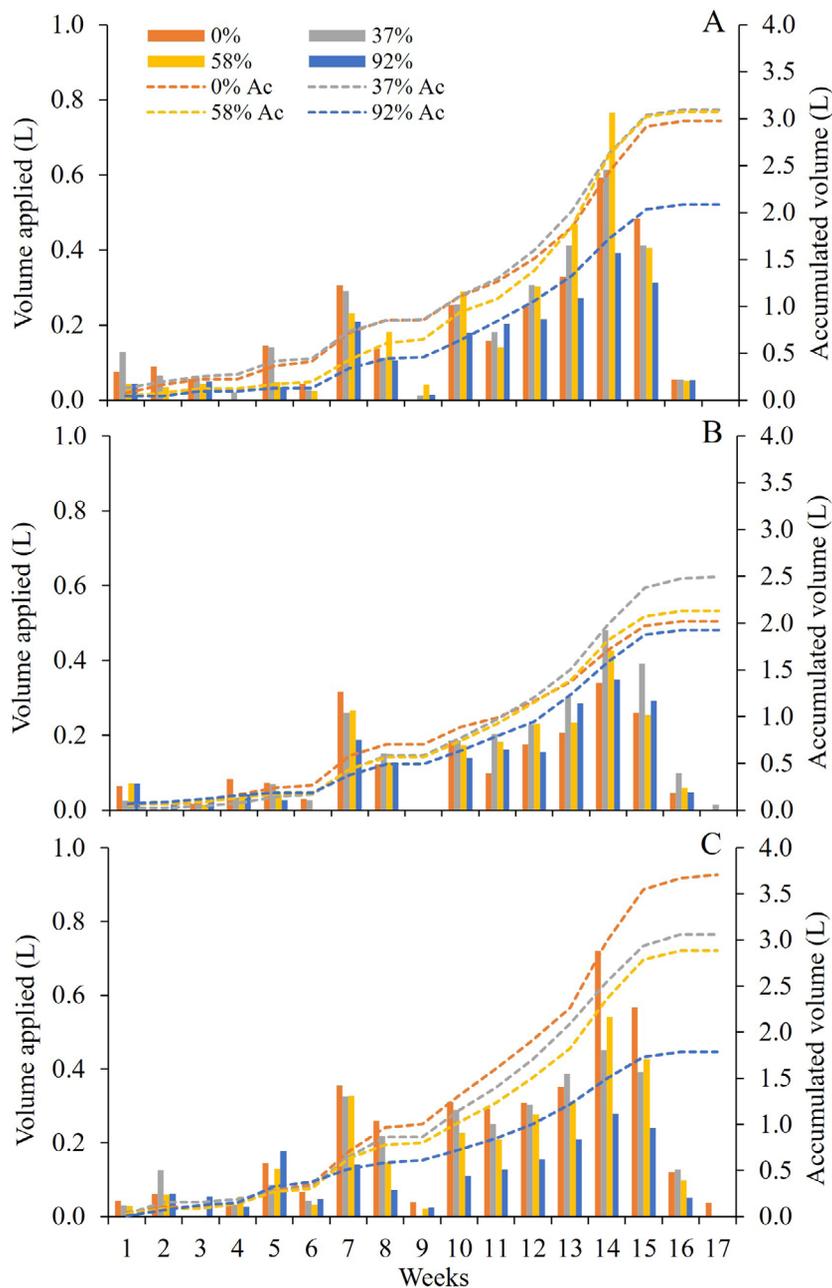


Figure 3: Weekly (bars) and accumulated (lines) water irrigation applied to the production of *D. nigra* (A), *A. leiocarpa* (B) and *H. courbaril* (C) seedlings, in three shading levels (37, 58 and 92%) and in full sun (0%).

Shading did not interfere in the shoot height of *H. courbaril*, which reached commercial standard (20 cm) with 82 DAE (Figure 4E). For stem diameter, only seedlings grown under full sun (C) and shading levels of 37 (S1) and 58% (S2) reached 5.0 mm (standard) (Souza Júnior and Brancalion, 2016) during the experimental

period (140 days). This information indicates that *H. courbaril* should be produced under full sun, because there will be no expenses with the acquisition and installation of shade nets and its production time is shorter compared to those under intense shading, despite the higher water consumption (Table 1).

Table 1: Mean irrigation information to produce tree species seedlings in three shading levels and in full sun, in the period from 28/07 to 2019/11/20.

Species	Treatment	Irrigation system activation	Average activation time (min)	Average of total volume applied (L per seedling)
<i>D. nigra</i>	C	45	3.1	2.973
	S1	55	2.6	3.094
	S2	48	3.2	3.075
	S3	48	2.1	2.087
	Mean	49	2.8	2.807
<i>A. leiocarpa</i>	C	47	4.7	2.018
	S1	54	2.3	2.493
	S2	46	2.3	2.129
	S3	47	2.2	1.924
	Mean	49	2.9	2.141
<i>H. courbaril</i>	C	58	3.2	3.708
	S1	52	2.8	3.063
	S2	48	3.0	2.885
	S3	46	1.9	1.784
	Mean	51	2.7	2.860

C: control (full sun); S1: 37%; S2: 58%; S3: 92% (shading levels).

Souza et al. (2010) studied the behavior of *H. courbaril* planted under full sun and in secondary forest enrichment strips and found higher growth of this species under full sun, although it is considered late secondary (Carvalho, 2003). On the other hand, Oliveira et al. (2011) claim that *H. courbaril* can regenerate and recruit in shaded environments, but growth is limited by low light conditions. These results, together with those obtained in the present study, discard the shading of 92% for the species.

Only the species *D. nigra* and *A. leiocarpa* showed significant height variations in response to different shading levels at the end of the experimental period (Figure 5A). For stem diameter (Figure 5B), the three species were influenced by shading levels. The values of 51.0 cm and 4.41 mm (S1), and 20.08 cm and 2.52 mm (S2) represent the highest averages of height and stem diameter, respectively, for the species *D. nigra* and *A. leiocarpa*. For *H. courbaril* seedlings, the highest average of height and stem diameter were 30.5 cm (S3) and 5.1 mm (S2).

D. nigra seedlings showed greater growth in height and stem diameter for S1 and S2, indicating a differentiated adaptation of the seedling under shading

from 37 to 58%. Leaf area (Figure 5C) and biomass (Figures 5D and 5E) also indicate higher average values under intermediate shading levels (37 and 58%). Dickson quality index (DQI) (Figure 5F) confirms the previous information and points to shading around 37% as being the most recommended.

The species *D. nigra* is a species considered late secondary (Carvalho, 2003), and therefore tolerates partial shading for its development, although it grows well in full sun. The high temperatures of the study site possibly resulted in more favorable conditions for this plant under the range of shading presented. Using plastic bags and subsoil-based substrate, Reis et al. (1991) and Pacheco et al. (2013) found better growth of seedlings under shading from 30 to 50% and from 50 to 84%, respectively.

The shading level of 58% (S2) promoted the highest averages of height (20.1 cm) and stem diameter (2.52 mm) for *A. leiocarpa* seedlings, while the conditions of full sun (C) and 92% shading (S3), respectively, led to the lowest average height (13.0 cm) (Figure 5A) and the smallest average diameter (1.98 mm) (Figure 5B). Shading levels between 58 and 92% and between 37 and 58% are considered ideal for shoot height and stem diameter, respectively.

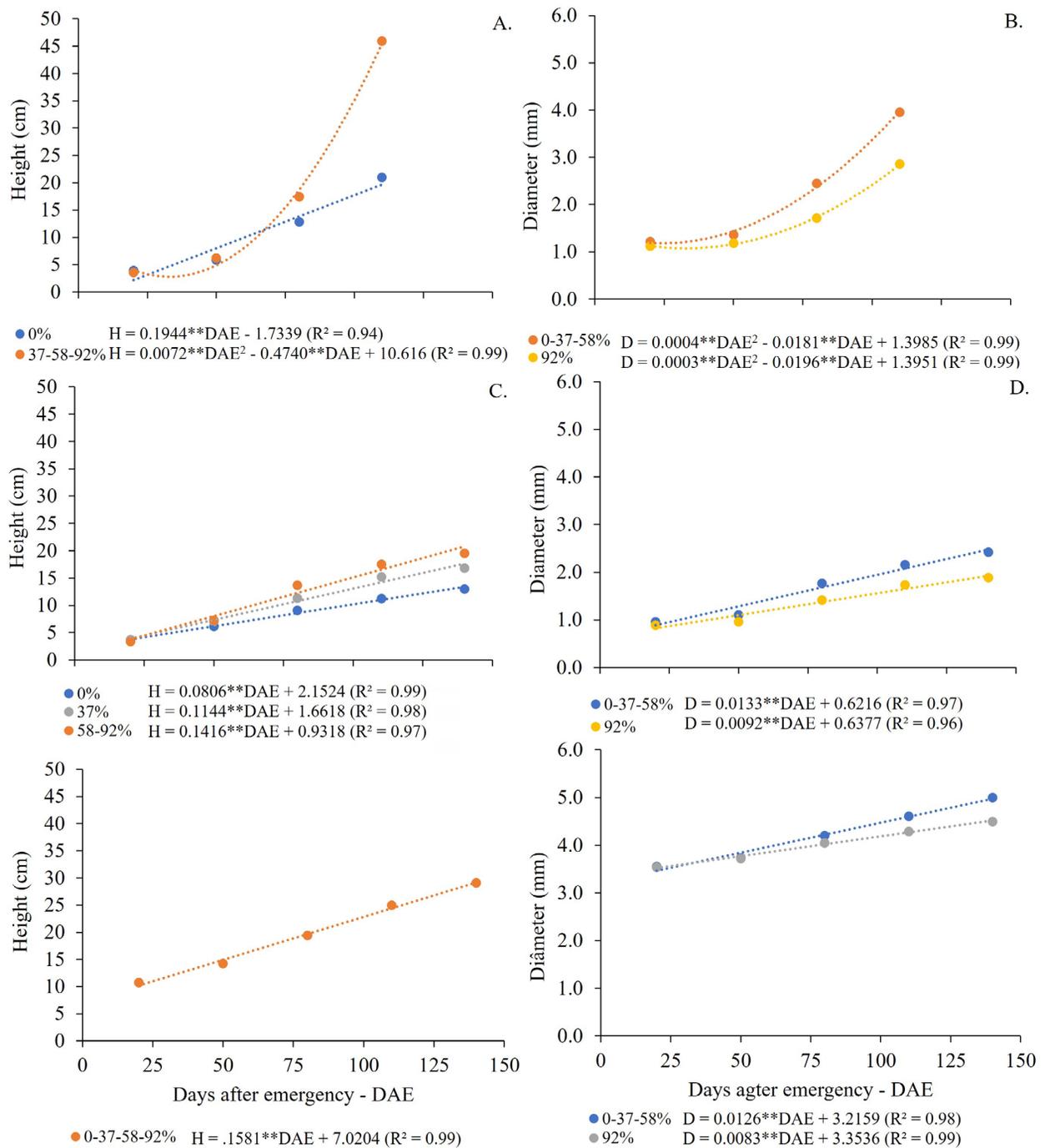


Figure 4: Growth in height and stem diameter of the seedling *D. nigra* (A, B), *A. leiocarpa* (C, D) e *H. courbaril* (E, F), over days after emergence produced in three shading levels and in full sun. ** significant at 99% of probability by t test.

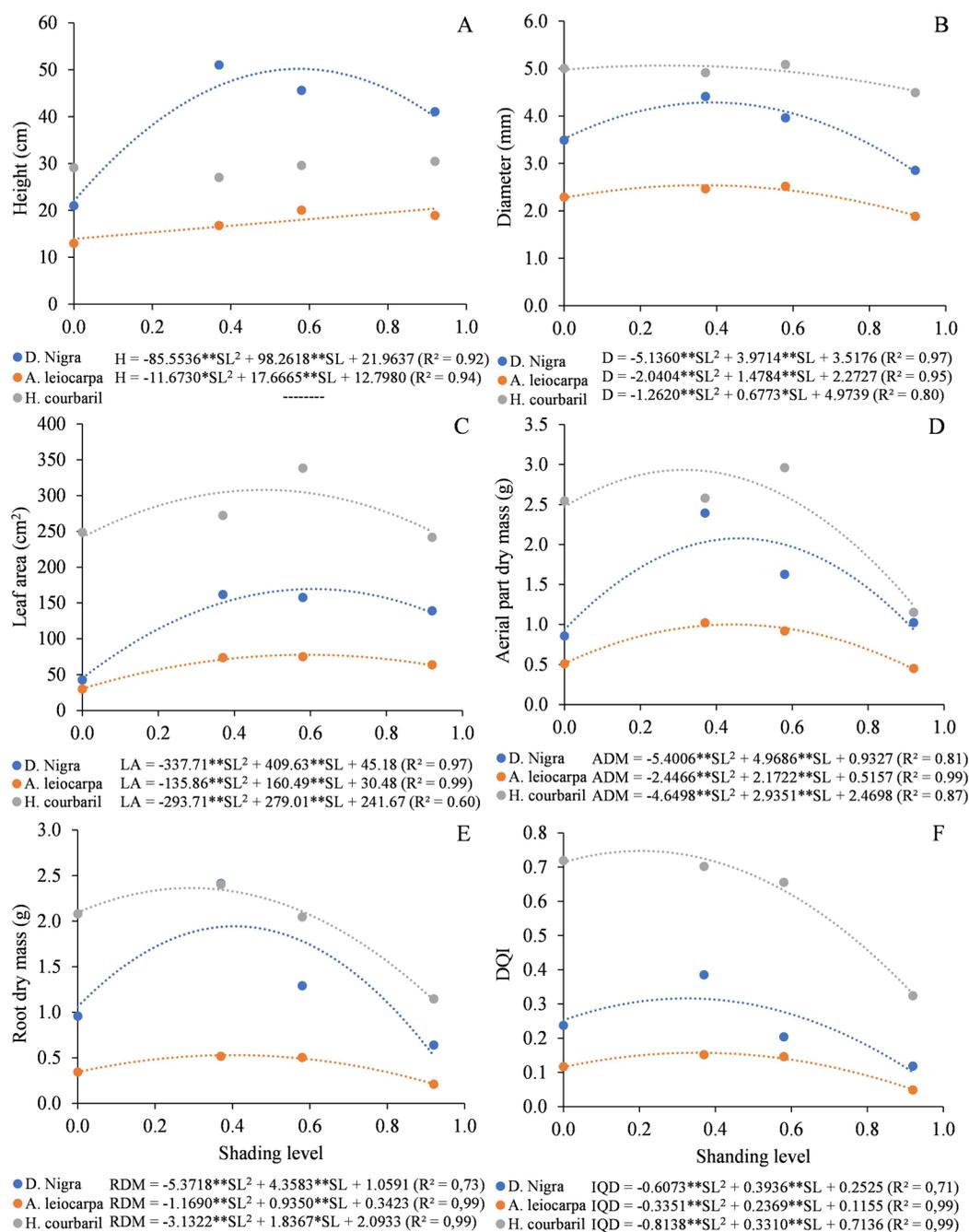


Figure 5: Variation in seedling height (A), stem diameter (B), leaf area (C), shoot dry mass (D) and root system mass (E) and Dickson quality index - DQI (F) for *D. nigra*, *A. leiocarpa* and *H. courbaril* at different shading levels. * significant at 95% and probability by t test; and ** significant at 99% probability by t test.

The highest values of average leaf area (Figure 5C) and biomass (Figures 5D, E) were obtained under intermediate shading levels, between 37 and 58%.

Values of shoot dry mass (SDM) (Figure 5D) higher than those of root dry mass (RDM) (Figure 5E) indicate that there is an ideal supply of nutrients (Schumacher;

Ceconi; Santana, 2004) and adequacy of the growth of these species to the substrate used. The average values of DQI (Figure 5F) confirm the previous trend and indicate that the shading of 37% promotes better quality for the seedlings compared to the shading of 58%. Thus, it is possible to infer that the ideal shading value for the species *A. leiocarpa* is around 50%.

There was no significant variation in shoot height for *H. courbaril* (Figure 5A) as a function of the shading levels, whereas for stem diameter (Figure 5B) the variation was small, but with better results for shading levels of up to 58%. The average leaf area (Figure 5C) and biomass (Figures 5D, E) showed higher values under intermediate shading, and DQI indicates a trend of higher seedling quality between the full sun condition and 37% shading (Figure 5F). For 92% shading, there is a significant reduction in the value of DQI, indicating low quality of the seedlings produced, although there is no variation in height and stem diameter with the other treatments. Thus, *H. courbaril* seedlings should be grown under full sun or under shading levels of up to 58%.

Evaluating the growth of *H. courbaril* seedlings, Lima et al. (2010) found higher growth in height and total dry mass with 50 and 80% shading, respectively. On the other hand, Silva et al. (2007) verified that this species is able to adjust to maximize the acquisition of light even under very limiting condition, as that caused by natural shading, so it is possible to produce seedlings in nurseries from the condition of full sun up to 50 or 70% shading. Campos and Uchida (2002) claim that the growth of *H. courbaril* seedlings were hampered when it was subjected to shading greater than 70%.

Regardless of the species, the highest volumes of water (Table 1) were applied in the treatments that promoted higher DQI (Figure 5F) and higher water productivity (WPI), for *D. nigra* and *A. leiocarpa* (Table 2). On the other hand, higher WPI values for *H. courbaril* were obtained with shadings of 37 and 58%, which received, respectively, 82.6 and 77.8% of the water volume applied in the full sun treatment.

H. courbaril seedlings presented values of WPI ranging from 0.561 to 1.735 g L⁻¹ under the different shading levels and variables evaluated. Despite the higher volume of water applied by irrigation compared to the others (Table 1), this species showed higher response in stem diameter, leaf area, shoot dry mass and root dry mass (Figure 5), indicating capacity for use in the formation of forest stands in regions that require forest restoration and have water restrictions.

On the other hand, values of WPI for *A. leiocarpa* ranging from 0.109 to 0.668 g L⁻¹, which is consistent with the lowest yield in all growth variables evaluated (Figure 5). Regardless of the species and variable used in the calculation, the light attenuation of 37% ensured seedlings with better growth, higher DQI and promoted the best results of irrigation water productivity (WPI).

Table 2: Irrigation water productivity (g L⁻¹) for tree species at different treatments.

Treatment*	Experiments/species		
	<i>D. nigra</i>	<i>A. leiocarpa</i>	<i>H. courbaril</i>
Shoot system dry mass			
C	0.287 C**	0.252 B	0.686 B
S1	0.773 A	0.408 A	0.842 AB
S2	0.528 B	0.431 A	1.026 A
S3	0.490 B	0.235 B	0.644 B
Root system dry mass			
C	0.322 B	0.171 B	0.561 A
S1	0.779 A	0.207 AB	0.784 A
S2	0.419 B	0.237 A	0.709 A
S3	0.307 B	0.109 C	0.642 A
Total dry mass			
C	0.609 B	0.423 B	1.247 B
S1	1.553 A	0.615 A	1.626 AB
S2	0.948 B	0.668 A	1.735 A
S3	0.797 B	0.344 B	B

*C: control (full sun); S1: 37%; S2: 58%; S3: 92% (shading levels). **Averages followed by the same capital letter in the column do not differ by the Tukey test, at 5% probability.

Keffer et al. (2019) obtained values of approximately 0.99, 1.83, 1.92, 1.28 and 1.11 g L⁻¹ in seedlings of Amazonian yellow Ipe after 82 days of cultivation, respectively, under full sun and shading levels of 35, 50, 65 and 80%. For *Dipteryx alata* Vogel, a species native to the Cerrado biome, Borella et al. (2020) found WPI values at 125 days after transplantation of 0.96, 1.12, 1.20, 1.06 and 1.43 g L⁻¹, respectively, for cultivation under full sun and black nets with 45.3, 54.1, 68.3 and 83.3% shading. Although these are other species, it can be noted that these values of WPI are compatible with those found in the present study, emphasizing that WPI is not only related to the species, but also to early growth

environment, which influences the water demand for seedlings.

The search for increasing WPI in forest nurseries should be stimulated, given that the water use efficiency is relatively low in agricultural production processes (Hsiao; Steduto; Fereres, 2007) and, consequently, there is low water productivity in irrigated systems (Kang et al., 2017). This objective can be easily achieved with the adoption of irrigation management, based on automatic application in response to seedling requirement, which contributes to the production of quality seedlings and water saving.

CONCLUSIONS

The highest volumes of irrigation are associated with the conditions that promoted the greatest development of the species, in general the intermediate conditions of shading or under full sun. The shading levels of 37 and 58% led to the best results for the species *D. nigra* and *A. leiocarpa*, respectively. *H. courbaril* can be grown under conditions of full sun and up to 58% shading. The highest values of irrigation water productivity are associated with intermediate shading levels (37 and 58%).

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REFERENCES

- ABREU, A. H. M. et al. Characterization and potential of formulated substrate with biosolids in *Schinus terebinthifolius* Raddi. and *Handroanthus heptaphyllus* (Vell.) Mattos seedling production. **Ciência Florestal**, 27(4):1179-1190, 2017.
- ALLEN, R. G. et al. **Crop evapotranspiration – Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56**. Rome: FAO - Food and Agriculture Organization of the United Nations 1998. 301p.
- ALLEONI, L. R. F.; FERNANDES, A. R.; CORREIA, B. L. Sequential extraction of phosphorus in an Oxisol amended with biosolids in a long-term field experiment in Brazil. **Agriculture, Ecosystems & Environment**, 161:145-151, 2012.
- ALVARES, C. A. et al. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, 22(6):711-728, 2013.
- ATAÍDE, G. M. et al. Alterações fisiológicas durante a hidratação de sementes de *Dalbergia nigra* (Vell.) Fr. All. ex Benth.). **Ciência Florestal**, 26(2):615-625, 2016.
- BORELLA, D. R. et al. Water requirement of *Dipteryx alata* Vogue seedlings at different solar radiation levels in Cerrado-Amazon transition. **Tropical and Subtropical Agrosystems**, 23(3):1-13, 2020.
- CALDEIRA, M. V. W. et al. Biossólido na composição de substrato para a produção de mudas de *Tectona grandis*. **Floresta**, 42(1):77-84, 2012.
- CALDEIRA, M. V. W. et al. Substratos alternativos na produção de mudas de *Chamaecrista desvauxii*. **Revista Árvore**, 37(1):31-39, 2013.
- CAMPOS, M. A. A.; UCHIDA, T. Influência do sombreamento no crescimento de mudas de três espécies amazônicas. **Pesquisa Agropecuária Brasileira**, 37(3):281-288, 2002.
- CARVALHO, P. E. R. **Espécies arbóreas brasileiras**. Colombo: Embrapa Florestas. 2003. 1040p.
- CÉSAR, F. R. C. F. et al. Crescimento inicial e qualidade de mudas de *Pterogyne nitens* Tull. conduzidas sob diferentes níveis de restrição luminosa artificial. **Ciência Florestal**, 24(2):357-366, 2014.
- COSTA, M. S. et al. Growth analysis of five Leguminosae native tree species from a seasonal semideciduous lowland forest in Brazil. **Dendrochronologia**, 36:23-32, 2015.
- DANTAS, B. F. et al. Taxas de crescimento de mudas de catingueira submetidas a diferentes substratos e sombreamentos. **Revista Árvore**, 33(3):413-423, 2009.
- DAVIDE, A. C. et al. Fatores que afetam a qualidade de mudas destinadas aos projetos de restauração de ecossistemas florestais. In: DAVIDE, A. C.; BOTELHO, S. A. (Eds.). **Fundamentos e métodos de restauração de ecossistemas florestais: 25 anos de experiência em matas ciliares**. Lavras: UFLA, p.181-274p. 2015.
- DELGADO, L. G. M. et al. Qualidade morfológica de mudas de ingá sob diferentes manejos hídricos. **Irriga**, 22(3):420-429, 2017.

- DICKSON, A.; LEAF, A. L.; HOSNER, J. F. Quality appraisal of white spruce and white pine seedling stock in nurseries. **The Forest Chronicle**, 36(1):10-13, 1960.
- DUMROESE, R. K. et al. Exponential fertilization of pinus monticola seedlings: Nutrient uptake efficiency, leaching fractions, and early outplanting performance. **Canadian Journal of Forest Research**, 35(12):89-97, 2005.
- ELOY, E. et al. Avaliação da qualidade de mudas de *Eucalyptus grandis* utilizando parâmetros morfológicos. **Floresta**, 43(3):373-384, 2013.
- GASSON, P. et al. Wood identification of *Dalbergia nigra* (CITES Appendix I) using quantitative wood anatomy, principal components analysis and naive bayes classification. **Annals of Botany**, 105(1):45-56, 2010.
- GOMES, D. R. et al. Lodo de esgoto como substrato para a produção de mudas de *Tectona grandis* L. **Cerne**, 19(1):123-131, 2013.
- GOMES, K. C. O. et al. Crescimento de mudas de garapa em resposta à calagem e ao fósforo. **Revista Árvore**, 32(3):387-394, 2008.
- GRAYBILL, F. A. **Theory and application of the linear model**. Belmont: Duxbury, 2000. 204p.
- HSIAO, T. C.; STEDUTO, P.; FERERES, E. A systematic and quantitative approach to improve water use efficiency in agriculture. **Irrigation science**, 25(3):209-231, 2007.
- KANG, S. et al. Improving agricultural water productivity to ensure food security in China under changing environment: From research to practice. **Agricultural Water Management**, 179(1):5-17, 2017.
- KEFFER, J. F. et al. Evapotranspiration and water sensitivity of Amazonian yellow ipe seedlings under different shading conditions. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 23(10):733-740, 2019.
- LACERDA, A. E. B.; KANASHIRO, M.; SEBBENN, A. M. Effects of reduced impact logging on genetic diversity and spatial genetic structure of a *Hymenaea courbaril* population in the Brazilian Amazon forest. **Forest Ecology and Management**, 255(3-4):1034-1043, 2008.
- LIMA, A. L. D. S. et al. Crescimento de *Hymenaea courbaril* L. var. *stilbocarpa* (Hayne) Lee et Lang. e *Enterolobium contortisiliquum* (Vell.) Morong (Leguminosae) sob diferentes níveis de sombreamento. **Acta Amazonica**, 40(1):43-48, 2010.
- LORENZI, H. **Árvores brasileiras: Manual de identificação e cultivo de plantas arbóreas nativas do Brasil**. 6. ed. Nova Odessa, SP: Instituto Plantarum de Estudos da Flora, v. 1, 2014. 361p.
- MEDICI, L. O. et al. Automatic controller to water plants. **Scientia Agrícola**, 67(6):727-730, 2010.
- MONTEIRO, E. B. et al. Water requirements and crop coefficients of tropical forest seedlings in different shading conditions. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 20(8):709-715, 2016.
- NASCIMENTO, H. H. C. D. et al. Análise do crescimento de mudas de jatobá (*Hymenaea courbaril* L.) em diferentes níveis de água no solo. **Revista Árvore**, 35(3):617-626, 2011.
- OLIVEIRA, W. L. D. et al. Regeneração e estrutura populacional de jatobá-da-mata (*Hymenaea courbaril* L.), em dois fragmentos com diferentes graus de perturbação antrópica. **Acta Botanica Brasilica**, 25(4):876-884, 2011.
- PACHECO, F. V. et al. Crescimento inicial de *Dalbergia nigra* (Vell.) Allemão ex. Benth. (Fabaceae) e *Chorisia speciosa* A. St.-Hil (Malvaceae) sob diferentes níveis de sombreamento. **Revista Árvore**, 37(5):945-953, 2013.
- PERTASSEK, T.; PETERS, A.; DURNER, W. HYPROP-FIT Software User's Manual, V. 3.0. **UMS GmbH, München**, Germany, 2015, 66p. Available at: <<http://www.soil.tu-bs.de>>. Accessed on: August, 01, 2020.
- REIS, M. D. G. F. et al. Crescimento e forma do fuste de mudas de Jacaranda-da-Bahia (*Dalbergia nigra* fr. aliem.), sob diferentes níveis de sombreamento e tempo de cobertura. **Revista Árvore**, 15(1):23-34, 1991.
- REIS, S. M. et al. Desenvolvimento inicial e qualidade de mudas de *Copaifera langsdorffii* Desf. sob diferentes níveis de sombreamento. **Ciência Florestal**, 26(1):11-20, 2016.
- SANTOS, J. F. C. et al. Wildfires as a major challenge for natural regeneration in Atlantic Forest. **Science of The Total Environment**, 650:809-821, 2019.
- SANTOS, R. B. et al. Planejamento da pulverização de fungicidas em função das variáveis meteorológicas na região de Sinop-MT. **Global Science and Technology**, 6(1):72-88, 2013.
- SCALON, S. P. Q. et al. Estresse hídrico no metabolismo e crescimento inicial de mudas de Mutambo (*Guazuma ulmifolia* Lam.). **Ciência Florestal**, 21(4):655-662, 2011.

- SCHINDLER U. A; MÜLLER, L. Simplifying the evaporation method for quantifying soil hydraulic properties. **Journal of Plant Nutrition and Soil Science**, 169(5), 623-629, 2006.
- SCHUMACHER, M. V.; CECONI, D. E.; SANTANA, C. A. Influência de diferentes doses de fósforo no crescimento de mudas de angico vermelho (*Parapiptadenia rígida* (Bentham) Brenan). **Revista Árvore**, 28(1):149-155, 2004.
- SILVA, B. M. D. S. et al. Efeito da luz no crescimento de mudas de *Hymenaea parvifolia* Huber. **Revista Árvore**, 31(6):1019-1026, 2007.
- SOUSA, T. J. S. et al. Mudras de *Luehea divaricata* produzidas com biossólido de duas estações de tratamento de esgoto. **Advances in Forestry Science**, 6(2):595-601, 2019.
- SOUZA JUNIOR, C. N.; BRANCALION, P. H. S. **Sementes e mudas**: Guia para propagação de árvores brasileiras. 1.ed. São Paulo: Oficina de textos, 2016. 464p.
- SOUZA, C. R. D. et al. Comportamento de espécies florestais em plantios a pleno sol e em faixas de enriquecimento de capoeira na Amazônia. **Acta Amazonica**, 40(1):127-134, 2010.
- TIAGO, P. V. et al. Genetic diversity and population structure of Jatobá: A species with economic potential for the Amazon region. **Ciência Florestal**, 28(2):515-524, 2018.