https://doi.org/10.1590/1678-992X-2023-0058

ISSN 1678-992X

SCIENTIA AGRICOLA

Research article

Treated cattle wastewater affects the growth, quality and water productivity of *Dalbergia nigra* seedlings produced with shading and irrigation levels

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Edited by: Thiago Libório Romanelli

Received April 06, 2023
Accepted September 13, 2023

ABSTRACT: The continuous demand for water in the agricultural sector has encouraged researchers worldwide to find alternatives to optimize this resource. The use of wastewater in irrigation is promising in this scenario, especially to produce tree seedlings. The growth, quality, and water productivity of *Dalbergia nigra* seedlings cultivated with sewage sludge were determined when irrigated with urban supply water (W_1) and cattle wastewater (CWW) treated for 1 h (W_2) and 2 h (W_3) of ozonation, considering four irrigation depths and shading levels (0 % (C_1), 37.6 % (C_2), 49.4 % (C_3), 75.8 % (C_4)). The height, stem diameter, biomass, and the Dickson Quality Index (DQI) were evaluated. The largest volumes of water applied in each experiment were 2.342 L per plant in W_2C_1, 2.114 L per plant in W_1C_3 and 1.556 L per plant in W_3C_1. The CWW provided satisfactory seedling growth, especially W_2, highlighting a DQI of 0.47 obtained in C_1 and better water productivity (3.8 g L^{-1}) in W_2C_1, with full depth. Using alternative inputs in the seedling production of tree species is a promising strategy and indicates benefits for waste disposal, such as sewage sludge and wastewater.

Keywords: Atlantic Forest, sewage sludge, ozonation, automated irrigation, biometric parameters

Introduction

Inadequate exploitation of water resources associated with increased demand presents a serious global challenge in which conflicts have emerged among productive sectors (Li et al., 2022). The agriculture, livestock, forest production, fishing, and aquaculture sectors already require 983.0 m^3 s^{-1} in Brazil (IBGE, 2020), with a forecast increase of approximately 60 % over the next 20 years (ANA, 2022).

Wastewater is a promising source, especially in the forestry sector, as it neither involves food production for human consumption nor poses a health issue (Salgot and Folch, 2018), and provides nutrients to seedlings (Lubello et al., 2004). Cattle wastewater (CWW) needs attention mainly because it can only be discarded with treatment in water bodies or for alternative application in agriculture (Silva et al., 2022). In connection with this, the use of treated CWW as irrigation water in nurseries becomes a sustainable alternative. However, results in the literature that support the recommendation of this practice are not yet available.

Water is essential to seedling production of tree species (Gabira et al., 2021), as it affects morphophysiological aspects related to growth and its rusticity (Sippel et al., 2018). However, the lack of adequate technique and management impairs the efficiency of irrigation systems and the quality of seedlings (Carvalho et al., 2021), thereby justifying the importance of determining the water requirement of tree species (Bueno et al., 2020).

Dalbergia nigra (Vell.) Allemão ex Benth (Jacarandá-da-Bahia) is a species native to the Atlantic Forest and, due to its natural durability and high value on the market, has been the target of inadequate exploration (Santos et al., 2021), as it is considered to be at high risk of extinction (Gasson et al., 2010). Lima et al. (2021) highlight the importance of the physiological and silvicultural understanding of the species, such as their adaptation to different levels of shading, as native species can present different responses in growth according to the level of luminosity (Ballestreri et al., 2021) and irrigation strategies (Bueno et al., 2021).

This study aimed to evaluate the growth of *D. nigra* seedlings when produced at levels of shading and irrigation with CWW treated by ozonation and fresh water. Plant growth was evaluated by their main biometric characteristics and water requirements.

Materials and Methods

The study was carried out in Seropédica, Rio de Janeiro, Brazil (22°45′21″ S, 43°40′28″ W, 33 m altitude), with an Aw climate, according to the Köppen 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). Three experiments were conducted simultaneously, which differed according to the type of water used for irrigation: supply water (control) (W_1), and CWW treated for 1 h (W_2) and 2 h (W_3) of ozonation (Souza et al., 2020). A randomized block design in a factorial scheme was adopted, and the *D. nigra* seedlings were evaluated at four shading levels (plots) and four irrigation levels (subplots), and four replications.

The *D. nigra* were sown on 26 Apr 2021, placing two seeds in each tube (280 cm^3) filled with pure biosolid (sewage sludge). This material originated from a wastewater treatment plant belonging to Companhia Estadual de Águas e Esgotos do Rio de Janeiro (CEDAE), from residential and commercial urban areas and did not contain industrial waste. The chemical characterization of the biosolid carried out in accordance with the official procedures contained in CONAMA Resolution 498 (MMA, 2020) indicated total values of macronutrients of 1.5 % N, 0.61 % P, 0.16 % K, 0.89 % S, 1.57 % Ca and 0.32 % Mg, plus 9.41 % organic carbon and for micronutrients, 722.7 mg kg^{-1} Zn, 20773.3 mg kg^{-1} Fe, 184.5 mg kg^{-1} Mn, 164.3 mg kg^{-1} Cu and 12.1 mg kg^{-1} B. The substrate had an apparent density of 0.74 g cm^{-3}, total porosity of 0.70 cm^3 cm^{-3}, and content of water of 0.37 cm^3 cm^{-3} at 10 kPa, according to the water retention curve, shown in Eq. (1).

$$\theta = 4.3^{-6} + \frac{0.72}{\left[1 + \left(0.27 * h\right)^{1.24}\right]^{0.44}} \tag{1}$$

where θ is the substrate moisture (cm cm^{-3}) and h the matric potential (kPa).

After the seedlings emerged, thinning was performed, although the taller and more centralized plants were always left intact. At 35 days after emergence (DAE) and with an average seedling height of around 7.5 cm, 24 tubes were placed in each plastic tray, in three rows with eight plants per row (Figure 1A). The trays were placed individually on metal benches coated with commercial polyolefin black agricultural screens, except those that remained unshaded. Using a digital luxmeter (mod. LD-400, Instrutherm), the illuminance of the roof was evaluated over five days, at intervals of 1 h, indicating 67.74 Lux (C_1), 41.43 Lux (C_2), 34.28 Lux (C_3) and 12.26 Lux (C_4), characterizing, respectively, treatments with 0 (unshaded), 37.6 %, 49.4 % and 75.8 % of attenuation.

Digital thermo-hygrometers (mod. HT-4010, Icel) were installed inside the benches with covers to determine relative humidity and air temperature. There was a data storage interval of 30 min. For the meteorological characterization in an unshaded condition, in addition to that recorded by the HT, data were recorded at a meteorological station of INMET (Instituto Nacional de Meteorologia), located close to the experiment. Having obtained the meteorological data, the reference evapotranspiration (ETo) was estimated daily by the Penman-Montheith (FAO-56) method (Allen et al., 1998). Furthermore, rain gauges were installed in an unshaded environment and inside each roof.

Cattle wastewater was collected at the SIPA experimental unit (Seropédica, RJ, Brazil) after preliminary treatment to remove the coarse solids (decanter) and anaerobic biological treatment (UASB reactor) with a hydraulic retention time of seven days, according to Souza et al. (2021). The CWW treatment by ozonation was carried out according to the methodology adapted by Souza et al. (2020), on a bench scale, using fixed-bed reactors built with PVC pipe 3″ in diameter and 0.7 m in length, filled with porous plastic medium (bio-rings), to 60 % of its volume. The oxidation process was carried out by placing a diffuser (20 µm pore size) at the bottom of the reactor connected by a hose to an O_3 generator (Ozone Generation, GL-3189A), with a flow rate of 1.3 L min^{-1}, purity of 92 % (± 2) and average concentration of 7.8 mg L^{-1} (± 1). A wad of tow or cotton was inserted into the reactor head to generate an internal atmosphere with a higher concentration of ozone, avoiding direct contact of the atmospheric air with the surface of the gas/liquid, and to absorb particles mobilized by the drag force of the gas (flotation process).

The average values of the physical-chemical parameters of the CWW after the UASB (crude), treated for 1 h (W_2) and 2 h (W_3) were, respectively: pH – 7.4, 7.6 and 7.8, electrical conductivity – 2.5, 1.8 and 1.6 dS m^{-1}, total solids – 970, 360 and 247 mg L^{-1}, turbidity – 231, 106 and 75 NTU, total organic carbon – 30.9, 4.3 and 3.1 mg L^{-1}, calcium – 17.8, 18.2 and 17.8 mg L^{-1}, total phosphorus – 17.4, 15.5 and 11.6 mg L^{-1}, magnesium – 13.2, 12.7 and 13.1 mg L^{-1}, ammonia nitrogen – 48.4, 26.8 and 18.8 mg L^{-1}, sodium – 33.6, 29.1 and 32.8 and sodium adsorption ratio – 2.0, 7.5 and 8.4.

Drip irrigation systems consisting of 16 mm polyethylene hoses and emitters (Netafim, mod. PCJ-HCNL) with nominal flows of 3.0, 2.5, 2.0 and 1.7 L h^{-1} were installed on each seedling tray (Figure 1B). They presented a distribution uniformity (DU) in excess of 95 %, according to Keller and Karmeli (1974). Water replacement was implemented automatically in response to the water requirement of the plants. This was achieved by using the simplified irrigation controller (SIC) proposed by Medici et al. (2010), which operates in response to soil/substrate water tension and is regulated by the level difference (LD) between a porous capsule (sensor) and a pressure switch, interconnected by a 9.5 mm polyethylene tube. The sensors, approximately 5-cm long, were made from commercial filter candles and installed in a tube filled with biosolid, in the same physical space as the growth roots (Figure 1C). Twelve controllers were used, one for each treatment, allowing the irrigation system to be activated independently in response to the development of seedlings in different shading and water used levels.

When the substrate matrix potential (SMP) reached a value corresponding to the LD, set at 40 cm, the pressure switch was activated, allowing the electric current to flow to the corresponding pump and solenoid valve, initiating the irrigation of the seedlings (Figure 1D). After wetting the substrate, the tension in the polyethylene tube was relieved by tripping the pressure switch at which point the electrical power was cut off and irrigation was interrupted. The water tensions in the activation and deactivation substrate corresponding to the difference in level adopted in the present study were monitored by Gomes et al. (2017) and confirmed the

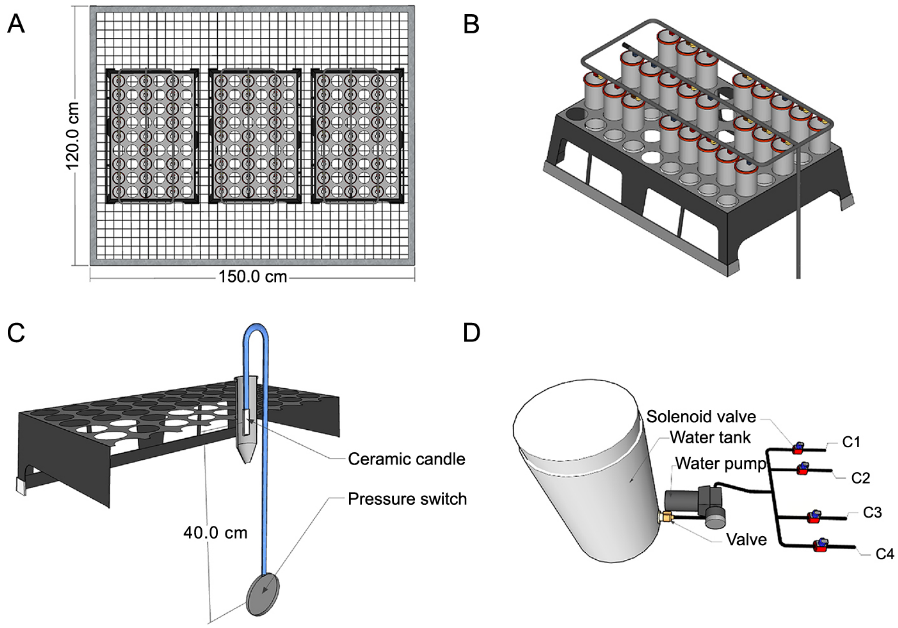

Figure 1 – Arrangement of trays on the metal bench (A); mesh emitters (B); lateral section indicating the positioning of the SIC in the tube; (C) and view of the pumping system coupled to the solenoid valves (D).

efficiency of the SIC, which was used in the irrigation of different crops (Bezerra et al., 2019; Cruz et al., 2022; Santos et al., 2020) as well as in the production of seedlings of tree species (Bueno et al., 2021, 2020; Carvalho et al., 2021). In addition, there was no drainage in the tubes, indicating that the water applied through the SIC was used effectively to develop the seedlings.

In each experiment and for each level of shading, CWW were installed in tubes irrigated with a 3.0 L h^{-1} emitter allowing for the replacement of 100 % (D_4) of the water requirement of the plants. Consequently, the seedlings irrigated with emitters of 2.5, 2.0 and 1.7 L h^{-1} received, proportionally, 83 (D_3), 67 (D_2) and 57 % (D_1) of the water requirement, respectively.

The irrigation system was supplied by independent 12 V motor pumps (NeoSolar SingFlo DP-160) based on water quality, powered by two 130 W photovoltaic modules (mod. YL140p-17b, Yingu Solar) connected to a battery (Bueno et al., 2021). To monitor the moment and time at which the treatments received irrigation water an electronic data collection and storage system was installed consisting of an Arduino Mega board programmed to perform readings every second, an SD memory card and voltage dividers (adapted by Bueno et al., 2021).

At 21 (01 June), 41 (21 June), 62 (12 July), 83 (02 Aug), 104 (23 Aug) and 122 (10 Sept) days after emergence (DAE), the seedlings were evaluated as to height (H) and stem diameter (D). After the last evaluation, when about 50 % of them acquired a standard expedition of 30 cm in height and 3.0 mm in diameter of the stem (Bueno et al., 2021), three seedlings were selected for destructive analysis. The plants were cut, separated from the aerial root system, placed in paper bags, and then in an oven at 65 °C until reaching constant mass. Shoot dry matter (SDM), root system dry matter (RSDM), and total dry matter (TDM) were determined. From the data obtained, the Dickson Quality Index (DQI) (Dickson et al., 1960) and irrigation water productivity (WPi) were determined, calculated by the ratio between TDM and the volume of water applied to irrigation.

For all the data sets collected, normality and homoscedasticity assumptions were tested to carry out the analysis of variance, using the Shapiro-Wilk and Bartlett tests, respectively, at 5 % probability, using the R software (R Core Team, 2022). Throughout the evaluation period, the H and D variables of the seedlings were compared for each shading level (C_1, C_2, C_3 and C_4), while at the end of the experiments, water productivity was evaluated for each cover and each level of irrigation. Statistical comparisons for each situation described and the nutrient extraction analysis were carried out by Tukey test ($p \leq 0.05$), using the Sisvar software (Version 5.8, Build 92).

At the end of the experiments and for each coverage and type of water used, a regression analysis was carried out, adjusting models between variables H, D, and DQI, and total volume received per seedling at 5 % probability of significance, using the same software.

Results

The volumes applied by irrigation were influenced by meteorological conditions, depending on the shading level (Table 1). Average daily solar radiation increased

Table 1 – Maximum and minimum relative temperatures and humidities, solar radiation and daily average ETo in the periods between the evaluations of the experiments.

Parameter*	Covering**	Days after emergence (DAE)				
		21-40	41-61	62-82	83-103	104-122
T_{max} (°C)	C_1	31.4	29.6	30.9	32.1	34.4
	C_2	30.1	28.2	29.7	31.3	33.3
	C_3	30.6	28.9	30.2	31.2	33.3
	C_4	30.1	28.6	29.8	30.5	33.0
T_{min} (°C)	C_1	17.3	14.3	12.9	16.0	19.5
	C_2	17.2	14.4	13.0	15.8	19.2
	C_3	17.2	14.5	13.1	15.8	19.3
	C_4	17.2	14.5	13.1	15.8	19.2
RH_{max} (%)	C_1	96.9	98.3	97.1	96.2	95.0
	C_2	96.5	96.9	94.7	95.2	94.8
	C_3	95.7	95.2	92.6	94.5	95.8
	C_4	97.6	97.6	94.2	95.6	94.9
RH_{min} (%)	C_1	54.1	50.9	42.6	47.0	48.2
	C_2	56.2	52.4	44.0	47.2	49.5
	C_3	55.4	52.8	43.8	48.5	51.2
	C_4	57.3	53.6	44.1	51.2	50.6
SR (MJ m^{-2} d^{-1})	–	11.24	11.98	13.25	13.70	14.42
ETo (mm d^{-1})	–	2.36	2.36	2.95	3.36	3.88

*T_{max} = maximum temperature; T_{min} = minimum temperature; RH_{max} = maximum relative humidity; RH_{min} = minimum relative humidity; SR = solar radiation; ETo = reference evapotranspiration. **C_1 = unshaded; C_2 = 37.6 %; C_3 = 49.4 %; and C_4 = 75.8 % attenuation.

over the evaluation periods, increasing the ETo, which reached 3.9 mm d^{-1} in the period 104 – 122 DAE. The Rs ranged from 2.10 (78 DAE) to 20.92 MJ m^{-2} d^{-1} (114 DAE), while the ETo ranged from 1.1 (94 DAE) to 6.8 mm d^{-1} (107 DAE), totaling 299.9 mm.

The volumes applied under the condition of 100 % water replacement (D_4) and those corresponding to precipitation at each shading level and periods between evaluations are also shown in Figures 2A-C. It rained throughout the entire evaluation period, which was sufficient to meet the demand of seedlings irrigated with W_1 and W_2, under a shaded condition, and with W_3 in the coverings C_3 and C_4, from 21 to 40 DAE. In general, the plants irrigated with W_3 required less water, and at C_1, the plants required 17.4 and 33.6 % less than when irrigated with W_1 and W_2, respectively, and 22.3 and 24.9 % less when grown at C_4.

The differences in height and diameter of *D. nigra* seedlings between the evaluation periods, at the different shading levels and types of irrigation water in the condition of 100 % water replacement (D_4) are shown in Figures 3A-F. Artificial shading influenced seedling height growth, especially in the last two evaluation periods at C_3 and C_4, regardless of the type of water used for irrigation. This result can be explained by the "shadow avoidance syndrome (SAS)", which refers to a set of ontogenic changes caused by changes in the light spectrum through signals to dedicated photoreceptor molecules that

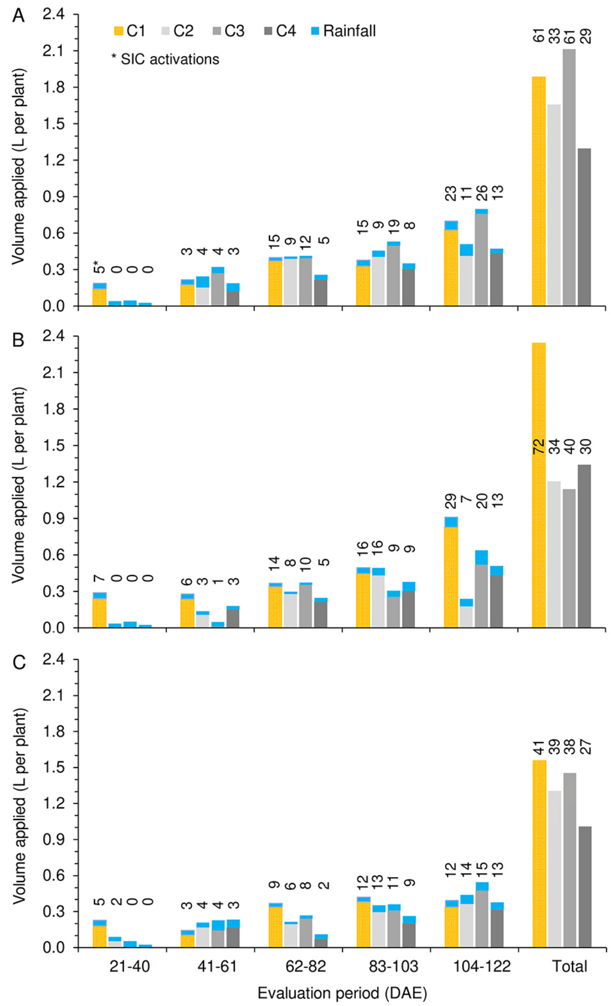

Figure 2 – Number of activations and volumes applied to *Dalbergia nigra* seedlings in the different treatment coverages with 100 % water replacement, for W_1 (A), W_2 (B) and W_3 (C). W_1 = control water; W_2 = bovine effluent ozonated for 1 h; W_3 = bovine effluent ozonated for 2 h; C_1 = unshaded; C_2 = 37.6 %; C_3 = 49.4 %; and C_4 = 75.8 % attenuation.

promote a series of growth responses in plants (Pierik and Ballaré, 2021).

The H and D values related to the volume applied per plant at the end of the evaluation period (122 DAE) for all shading levels, water types and emitters are shown in Figures 4A-F. The best fits were obtained with the linear model, with a positive response of H and D compared to the increase in the applied volume. Regardless of the type of water used, the *D. nigra* seedlings grown in C_4 showed a higher growth rate (higher angular coefficients) and required less volume to reach a greater height. Except for the treatment with 57 % water replacement (D_1) using W_1 and W_3, the C_4 shading level provided growth of seedlings with the recommended expedition pattern for the species 30 cm in height and 3 mm in diameter (Bueno et al., 2021).

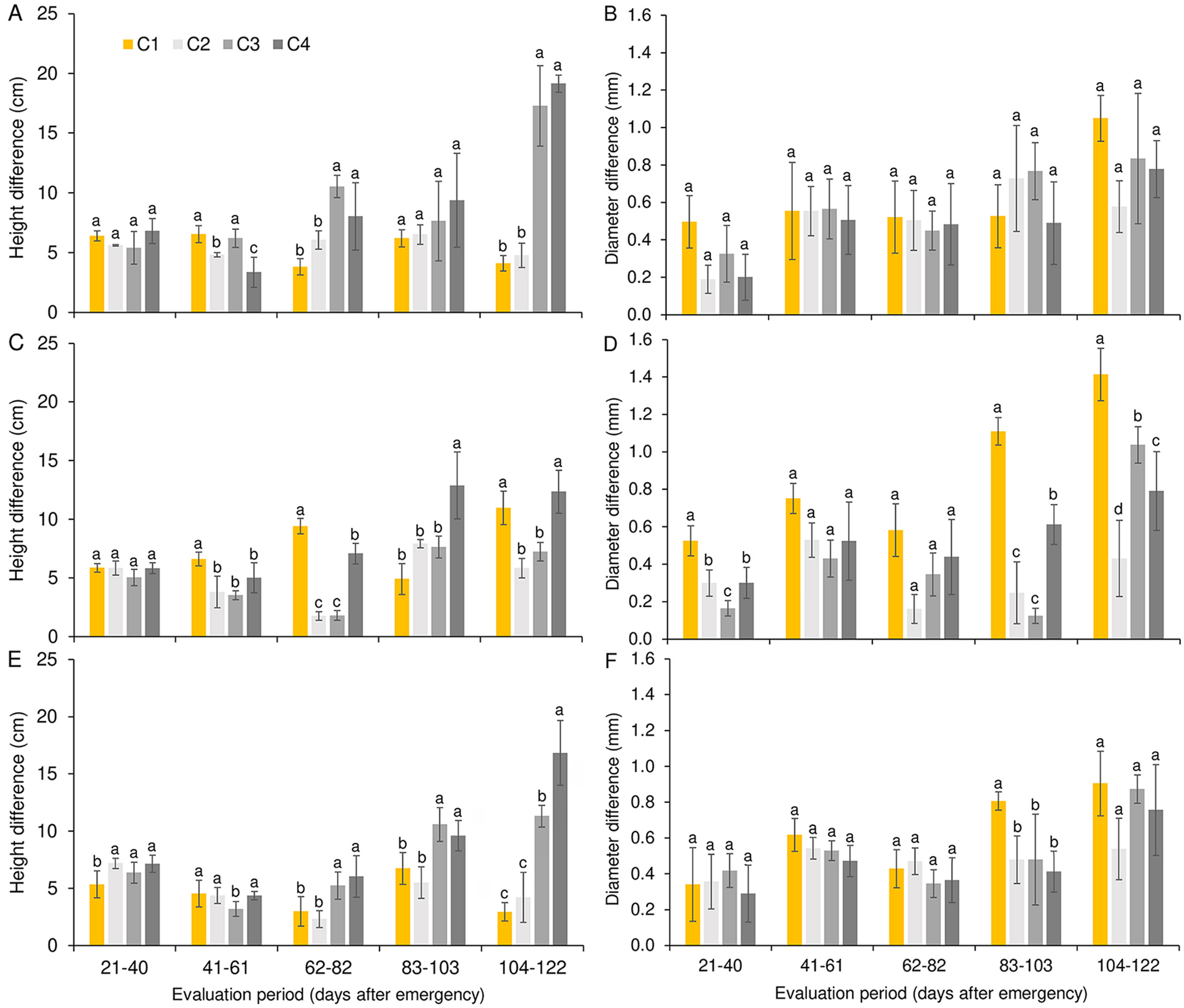

Figure 3 – Growth in height (left) and diameter (right) of *Dalbergia nigra* seedlings, between evaluation periods, in unshaded conditions (C_1) and covered (C_2, C_3 and C_4), in the treatment with 100 % water replacement, in types of water A and B (W_1 = control water), C and D (W_2 = CWW treated at 1 h) and E and F (W_3 = CWW treated at 2 h). ($p < 0.05$).

The DQI values for the seedlings as a function of the volume applied to each type of water are presented in Figures 5A-C. The highest indices were obtained at C_1, achieving values higher than the other coverages in all volumes applied with W_1 and W_2, except for the highest deficit condition (D_1) when W_3 was used. In an unshaded environment, seedlings reached an average DQI of 0.22 in W_1, ranging from 0.25 to 0.47 in W_2 and 0.13 to 0.27 in W_3. The worst indices were obtained in C_4 for seedlings irrigated with W_1 and W_3, ranging from 0.07 to 0.10 and 0.08 to 0.11, respectively, and in W_2 in the intermediate coverings (C_2 and C_3), with average DQI of 0.07 in both cases.

The water productivity values (WPi) obtained for the different replacement and shading levels for the three types of water used are presented in Figures 6A-F. Water productivity is a parameter that relates how much water the plant used to reach the biomass produced (g L^{-1}) and, therefore, the values obtained in W_2 by the seedlings grown in an unshaded environment (C_1) stand out (Figure 6C), being statistically superior in D_1, D_2 and D_4, reaching 3.8 g L^{-1} in 100 % volume. In W_1, there was no statistical difference between the two smallest volumes applied (D_1 and D_2), in which C_4 was more efficient in conversion when the total volume required by the plant was supplied. The seedlings irrigated with W_3 (Figures 6E and F) performed better than W_1 in absolute values, in which the seedlings conducted in C_4 stood out from the others. The results using W_1 (Figures 6A and B) were superior to those obtained by Bueno et al. (2021), urpassing the values found in C_2.

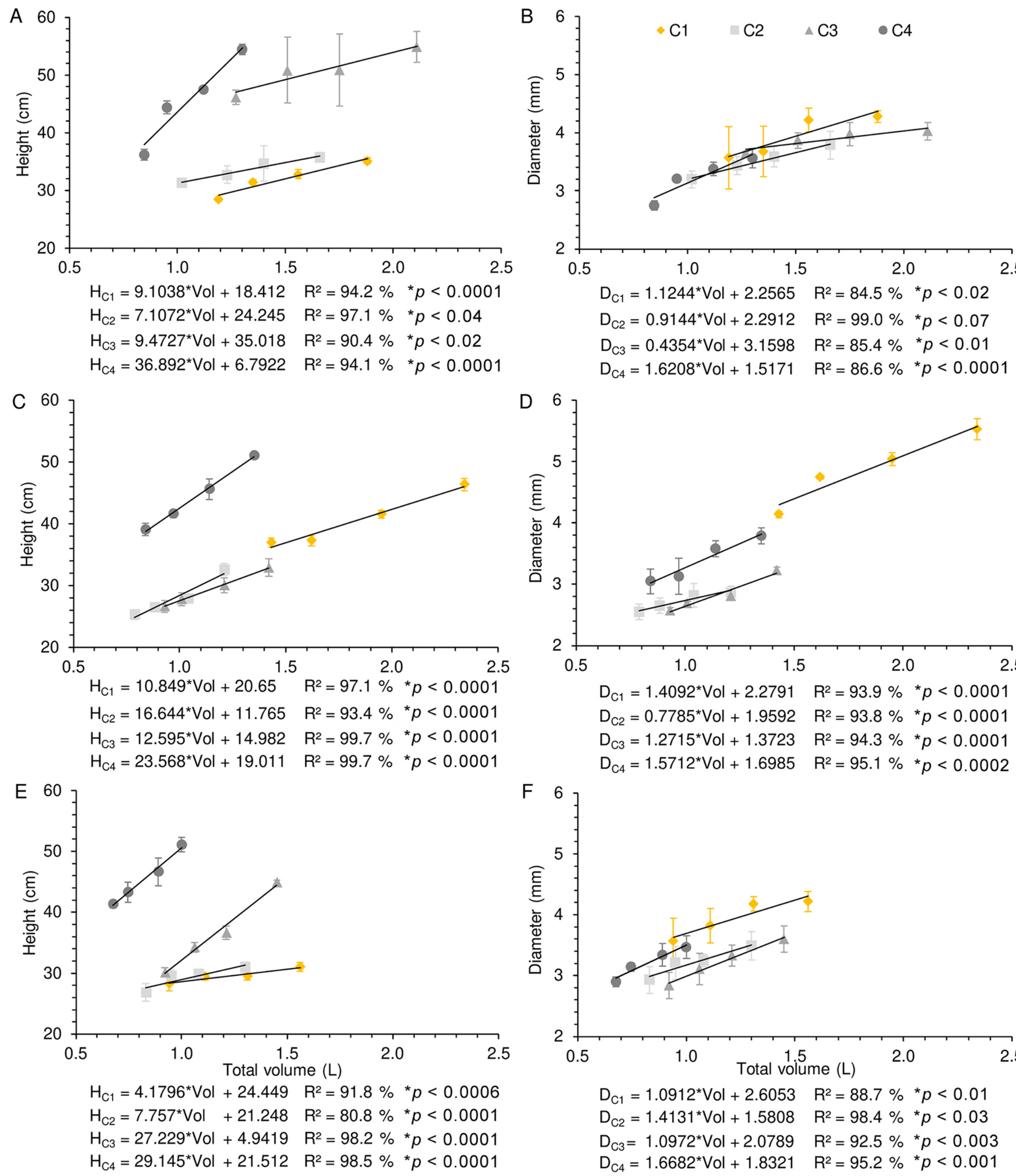

Figure 4 – Growth of *Dalbergia nigra* seedlings in height (left) and diameter (right) in relation to the irrigated volume. The points represent the four water depths applied; adjustments were made with average values achieved in each water regime. A and B (W_1 = control water), C and D (W_2 = CWW treated at 1 h) and E and F (W_3 = CWW treated at 2 h).

Discussion

In the period from 21 to 40 DAE, there were few activations of the irrigation system, and the amount of rainfall was sufficient to meet the water needs of the seedlings. On the other hand, 67 % of the activations occurred in the last two evaluation periods (83-103; 104-122), corresponding to more than 58 % of the volume of water applied. Activation of the irrigation system was more frequent in C_1, with 61, 72, and 41 times in W_1, W_2 and W_3, respectively, while in the highest shading level (C_4), the activations occurred only 29, 30, and 27 times (Figures 2A-C). Plants cultivated with W_2 in an unshaded condition (C_1) were irrigated in more than half of the experimental days (57 days), followed by plants cultivated with W_1 in coverages C_1 (50 days) and C_3 (43 days). There were days with more than one activation, which generally increased over the evaluation periods in

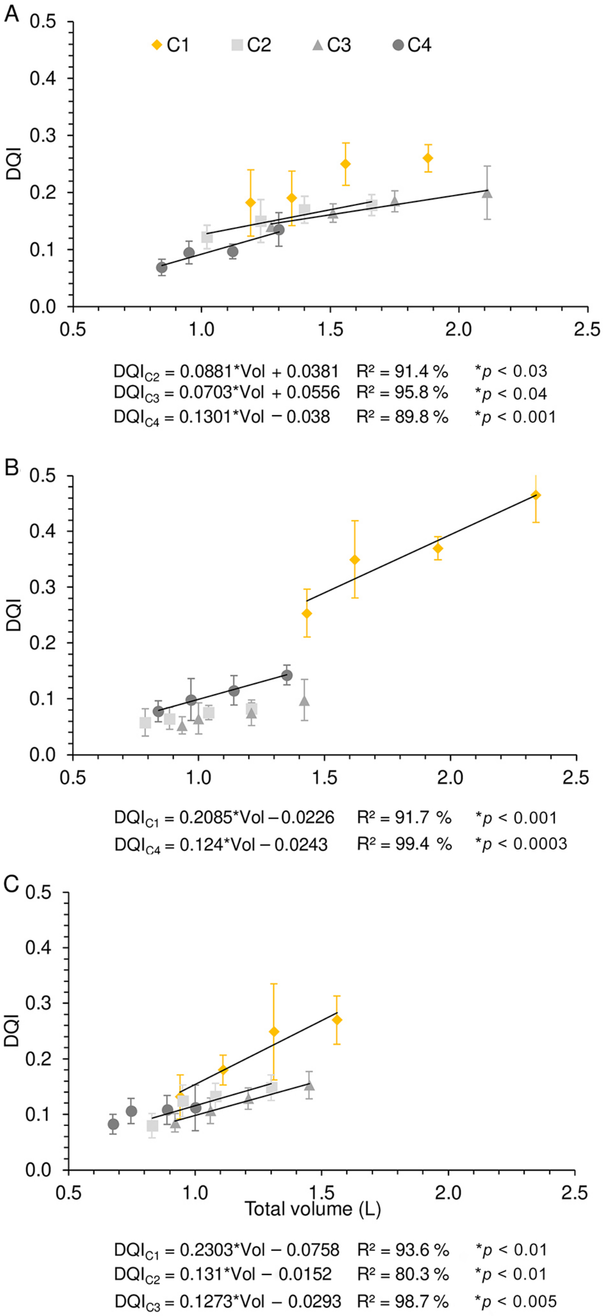

Figure 5 – Dickson Quality Index (DQI) in relation to the total volume received per plant. The points represent the four water depths applied, and adjustments were made with average values achieved for each water regime. A (W_1 = control water), B (W_2 = CWW treated at 1 h) C (W_3 = CWW treated at 2 h).

response to seedling growth and increased atmospheric evaporative demand (ETo).

The largest volumes of water applied in each experiment were 2.342 L per plant in W_2C_1, 2.114 L per plant in W_1C_3, and 1.556 L per plant in W_3C_1. These volumes are lower than those applied by Bueno et al. (2021), who, using control water (W_1), evaluated the growth of *D. nigra* seedlings for 115 days, arriving at an average ETo of 3.8 mm d^{-1}, 28 % higher than that observed in the present study (3.0 mm d^{-1}). The values found in both studies show the accuracy of the irrigation management carried out by the SIC (Medici et al., 2010), as the plants' requirements were met according to the local meteorological conditions.

Higher growth values in collar diameter were obtained for the seedlings conducted in C_1 (Figures 3A-F). In unshaded conditions, seedlings can translocate photoassimilates to the stem to better establish themselves under adverse conditions. This behavior was also observed in two other species, such as Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook) (Liu et al., 2018) and white oak (*Quercus insignis* M. Martens & Galeotti) (Montes-Hernández and López-Barrera, 2013). On the other hand, in situations of lower luminosity (C_3 and C_4) a high H/D ratio was observed, indicating etiolation of the seedlings as a physiological response to the shade (Grime, 2006).

When irrigated with W_2, the seedlings showed lower growth in H and D in the intermediate coverings (C_2 and C_3). The high concentration of organic matter in the irrigation water favored the formation of crusts (biofilm) on the surface of the tubes, creating a physical barrier for evaporation and infiltration of water into the substrate (Rossi et al., 2017). In fact, the lower supply of water and nutrients may have impaired plant growth during this period.

The highest volumes of water applied to *D. nigra* seedlings were observed at shading levels C_3 and C_1, in W_1 and W_2, respectively, contributing to the achievement of the desired expedition standard. When irrigated with W_3, the seedlings conducted at C_1 required the highest volume of water. However, this was not reflected in an increase in growth since the recommended minimum height (30 cm) was reached only with the highest flow emitters (D_4). Furthermore, it was noted that in W_3C_1, the diameter of the seedlings was visibly greater than under shading conditions (C_2, C_3, and C_4), reinforcing the theory that for species with secondary growth, the survival strategy in full light is rapid fixation and survival, investing in height only after its establishment. Additionally, Figures 4A-F show that the plants that received less water took longer to reach the desired shipping pattern. For Bueno et al. (2021), producing quality seedlings in less time is essential decision-making. However, other aspects need to be considered, such as efficiency in water and energy use, organically integrating social precepts and environmental and economic aspects of sustainable production.

In general, seedlings of better quality (DQI) were produced applying W_2 (Figure 5B), whose concentration of nutrients especially favored growth in diameter (Figure 4D) and, consequently, the accumulation of dry matter. Using CWW, Silva et al. (2022) found that lower exposure to ozonation promoted higher concentrations

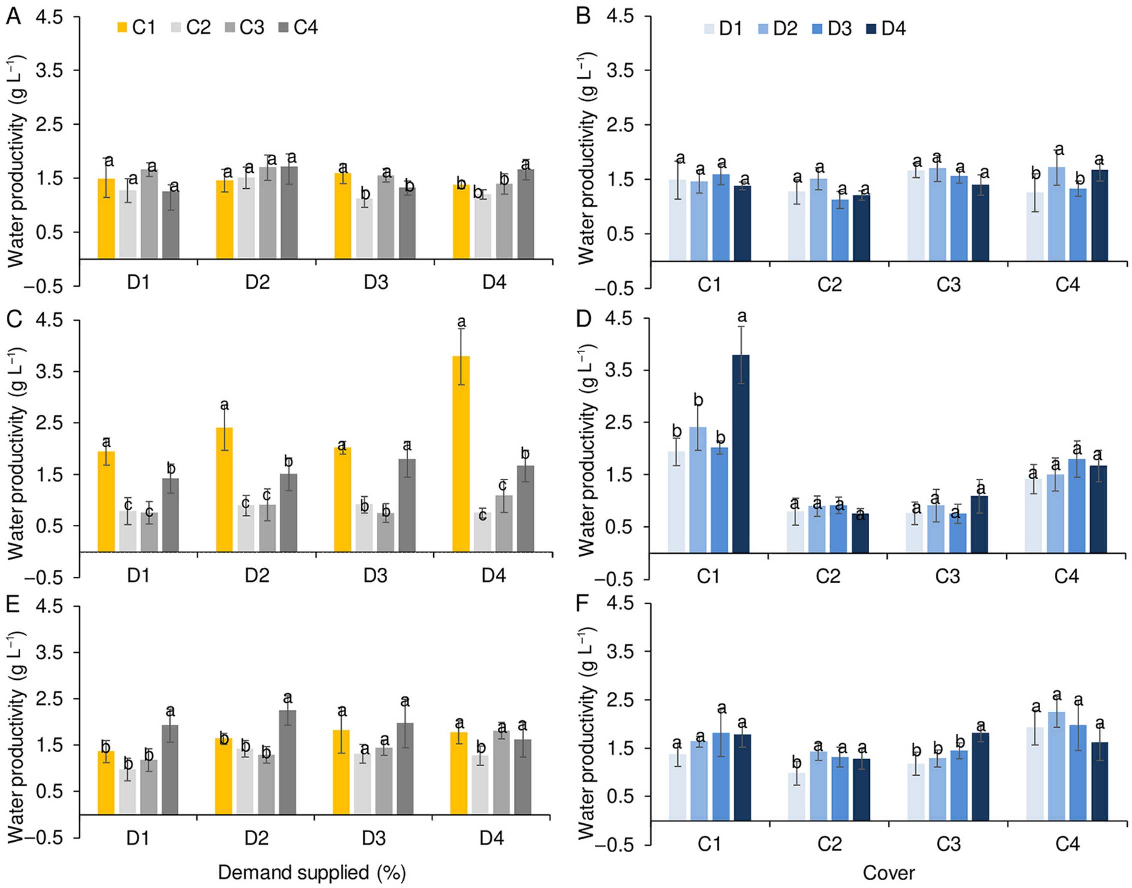

Figure 6 – Water productivity as a function of water replacement (D_1 = 57 %, D_2 = 67 %, D_3 = 83 % and D_4 = 100 %) in the different coverages (on the left) and as a function of the shading level (C_1 = unshaded; C_2 = 37.6 %; C_3 = 49.4 %; and C_4 = 75.8 % attenuation) in the different volumes applied (on the right), in the types of water W_1 (A and B), W_2 (C and D) W_3 (E and F) (W_1 = control water; W_2 = bovine effluent ozonated for 1 h; W_3 = bovine effluent ozonated for 2 h).

of P, N, and organic matter, which constitute interesting results for agricultural use of O_3 as an enhancer of substrate fertility. It is worth mentioning that the success of forest restoration depends on planting quality seedlings with excellent growth potential (Grossnickle and MacDonald, 2017). Thus, the DQI becomes a seedling evaluation criterion, relating morphological parameters of height, diameter, and plant biomass, and higher values of this index indicate seedlings with better quality at the time of planting.

The seedlings had a better conversion (WPi) in C_1, for absolute values, for a water deficit of 16.7 % (D_3), when irrigated with W_1 and W_3. With W_1, it is worth highlighting the values reached by the seedlings when irrigated with D_2, which at no shading level differed statistically from D_4 (Figures 6A and B). Therefore, when irrigated with water from the local supply, *D. nigra* seedlings can be efficient in the use of water even if their needs are not 100 % met (Figure 6B). This finding is also present with W_2 for seedlings grown at certain shade levels (C_2, C_3, and C_4) (Figure 6D) and with W_3 especially for seedlings grown at C_1 and C_4 (Figure 6E).

In addition to better quality, the highest WPi values were also obtained with W_2, even under a condition of greater deficit, being higher than those reported by Keffer et al. (2019) (1.92 g L^{-1}) in seedlings of Amazonian yellow Ipe, and by Borella et al. (2020) (1.43 g L^{-1}) for *Dipteryx alata* Vogel, under different light conditions. Although these are different plant species, Bueno et al. (2021) point out that WPi is not only related to the species, but also to the early growth environment, which influences the water demand for seedlings. Thus, the search for increasing WPi in forest nurseries should be encouraged and can be achieved with the proper irrigation management associated with the use of treated CWW.

In Brazil, seedling production systems in forest nurseries do not use irrigation management techniques, and due to a lack of knowledge of their water needs, different species are produced with excessive water application. Associated with the lack of management, the use of wastewater has also not been used by nurseries. In this work, we evaluated the use of treated CWW in the irrigation of *D. nigra* seedlings at different levels of water supply and shading. The results of this work confirm our first hypothesis that the growth of *D. nigra* is not impaired using treated CWW in irrigation. On the contrary, the use of W_2 favored the growth of seedlings when conducted in an unshaded environment and with W_3 when conducted at greater shading levels. The seedlings were responsive to shading levels, especially in terms of height, where the samples taken at C_4 were superior to the others, regardless of the type of water used. When evaluated separately, the DQI was higher in *D. nigra* seedlings grown in an unshaded environment since the robustness desired by the plant depends on the relationship between height, diameter and biomass produced. The volumes of 2.342 L per plant in W_2C_1, 2.114 L per plant in W_1C_3 and 1.556 L per plant in W_3C_1 can be used as a reference for seedling production in commercial nurseries, considering the same environmental conditions. Higher water productivity values were obtained with treated CWW, with *D. nigra* seedlings reaching 3.8 g L^{-1} in 100 % conversion volume to W_2C_1. The applied deficits did not prevent the growth of *D. nigra* seedlings, contrary to the hypothesis raised initially, and, in certain situations, led to better use of water by the plant than when the total water required was applied. The use of alternative inputs in the production of forest seedlings is recommended and encouraged; the results are promising and indicate benefits from waste disposal such as sewage sludge and wastewater in the production of tree species.

Acknowledgments

We thank the Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), and the Universidade Federal Rural do Rio de Janeiro (UFRRJ), specifically the Postgraduate Program in Agronomy – Soil Science (PPGACS), Water and Soil Research Group in Agricultural Systems (GPASSA), Microalgae and Interfaces Research Group (GPMI) and Reforestation Research and Studies Laboratory (LAPER).

Authors' Contributions

Conceptualization: Silva LO, Mendonça HV, Leles PSS, Carvalho DF, **Methodology:** Silva LO, Mendonça HV, Leles PSS, Carvalho DF. **Investigation:** Silva LO, Conforto BAAF, Carvalho DF. **Data Curation:** Silva LO, Conforto BAAF, Carvalho DF. **Writing – Original Draft:** Silva LO, Conforto BAAF, Carvalho DF. **Writing – Review & Editing:** Silva LO, Carvalho DF. **Funding acquisition:** Carvalho DF.

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