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Irrigation frequency and vermiculite proportion in substrate for *Eucalyptus grandis* seedling

Frequências de irrigação e proporção de vermiculita em mudas de *Eucalyptus grandis*

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Highlights:
How many times a day should we irrigate eucalyptus seedlings in less technified nurseries?
Twice the ETo was the amount of water used for the irrigation of the eucalyptus seedlings.
It takes 295 litres of water to produce 1 kg of dry eucalyptus biomass.
Two daily irrigations are sufficient for the production of eucalyptus seedlings.
The substrate with 80% vermiculite should be used for the production of eucalyptus seedlings.

Abstract

This study aimed to determine the best irrigation frequency and vermiculite proportion in substrate for *Eucalyptus grandis* seedling production in poorly technified nurseries. The experiment was carried out in Chapadão do Sul - MS (Brazil) from April 8 to July 23, 2013 (106 days). The experimental design was in randomized blocks arranged in a split-plots, with four irrigation frequencies (plots) and five vermiculite proportions (subplots) and six replications. Irrigation depth was estimated by the reference evapotranspiration (Penman-Monteith) multiplied by a crop coefficient (Kc) of 2. Average daily irrigation depth was 5.5 mm during the experimental period. The results showed that two daily irrigations (at 11:00 a.m. and 7:00 p.m.) and filling tubes with 80% vermiculite and 20% soil were most suitable for eucalyptus seedling production under these experimental conditions.
Key words: Eucalyptus. Irrigation management. Forestry. Substrate. Irrigation scheduling.

Resumo

Objetivou-se determinar as melhores frequências de irrigação e proporção de vermiculita em substrato para produção de mudas de *Eucalyptus grandis* em viveiros menos tecnificados. O experimento foi realizado entre 08/04/2013 e 23/07/2013 (106 dias) e conduzido em Chapadão do Sul-MS, Brasil. O delineamento experimental foi em blocos casualizados, em parcelas subdivididas, tendo nas parcelas

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quatro frequências de irrigação e nas subparcelas cinco proporções de vermiculita, com seis repetições. A lâmina de irrigação foi estimada pela evapotranspiração de referência (Penman-Monteith) multiplicada pelo coeficiente de cultivo (Kc) = 2. A lâmina média diária de irrigação no período experimental foi de 5,5 mm. Constatou-se que o manejo com duas irrigações diárias (11:00h e 19:00h) e preenchimento de tubetes com 80% de vermiculita e 20% de solo de barranco é mais indicado para a produção de mudas de eucalipto nessas condições.

Palavras-chave: Eucalipto. Manejo de irrigação. Silvicultura. Substrato. Turno de rega.

Introduction

The genus *Eucalyptus* stands out among the most cultivated forest species in Brazil. In 2015, the planted area covered 5.56 million hectares, which stands for 71.9% of the total forestry area (Felippe et al., 2016). It is a forestry species of high economic relevance for Brazil (Morais, Silva, & Rosa, 2018). Among Brazilian states, Mato Grosso do Sul stands out for its flatter terrain, which favors mechanized silviculture, and for having high-permeability soils. These added to a lack of soil loss through erosion in eucalyptus cropping (Guimarães et al., 2017), makes it a profitable and sustainable agricultural activity in that state.

Success in high-productivity forests depends mainly on seedling quality to produce material suitable for industrial purposes, also involving research with other elements, including substrates (Ehlers & Arruda, 2014; Kratz & Wendling, 2016; Michael, Yu, Wintle, Doronila, & Yuen, 2019). The substrate is the medium in which the roots grow and develop, giving structural support to the seedling shoot and providing water, nutrients, and oxygen necessary for proper plant development (Dutra, Grazziotti, Santana, & Massad, 2015).

Research on substrate compositions for tube-type containers has been intensified since the 1980s in Brazil (Mendonça, Ribeiro, Assunção, Freitas, & Souza, 2016) when the need to test vermiculite substrates had been already emphasized. Vermiculite substrate can be mixed with soil, but their correct proportion is essential for seedling quality and low production costs.

Another important factor for seedling production is irrigation, mainly in poorly technified nurseries. A proper water replacement is fundamental during seedling formation and development stage. According to C. R. A. Silva, Ribeiro, Oliveira, Klippel and Barbosa (2015), at this stage, irrigation depth varies from 4 to 16 mm day^{-1} in nurseries for eucalyptus seedling production in Brazil. Such a wide range is due to the wide Brazilian climate diversity. Therefore, general guidelines could lead to either deficit or over-application of water on forest seedlings.

The ideal water depth to be applied must be based on parameters such as plant, irrigation system, and weather conditions at the production site. In general, irrigation is carried out with a high frequency and in an amount higher than the water required by plants, causing waste of water (Freitag, Morais, & Nishijima, 2012). In addition, excess water can cause seedling losses due to hypoxia (Medina et al., 2019) or diseases, leading to shriveling and chlorosis of leaves and negative root geotropism (Silva et al., 2015). Another important factor to be considered is that excess water can cause the leaching of nutrients in the substrate, negatively influencing seedling development, besides providing a microclimate favorable to disease development (Freitag et al., 2012, Queiroz, Pereira, Silva, Fonsenca, Martins, 2017).

On the other hand, water deficit can lead to water stress and decrease nutrient absorption by plants. Also, the scarcity of this resource drastically affects plant metabolism, inducing the closure of the stomata to prevent water loss through transpiration, which leads to a reduction in photosynthetic activity and a series of other processes in plants (Freitag et al., 2012; Silva et al., 2015; Tatagiba et al., 2015).

Irrigation scheduling or frequency in poorly technified nurseries deserves special attention. Small volumes of the substrate where seedlings develop have low water storage capacity (Tatagiba et al., 2015). Thus, low-irrigation frequency can lead to water deficit and significant losses in forest seedling production, even generating mortality. On the other hand, high-irrigation frequencies provide high labor costs. Therefore, research is necessary to identify the best irrigation frequency and times, as well as the best proportion between vermiculite and soil in substrates for *Eucalyptus* seedlings, to guarantee forest seedlings with better quality in poorly technified nurseries.

In this sense, this study aimed to determine the best irrigation frequency and proportion between vermiculite and soil in the substrate for eucalyptus seedling production in poorly technified nurseries.

Material and Methods

Site characterization

The experiment was carried out from April 8 to July 23, 2013 (106 days), a season coincident with the eucalyptus seedling production in poorly technified nurseries in the municipality of Chapadão do Sul, MS, Brazil. The study was conducted in an experimental area belonging to the Federal University of Mato Grosso do Sul. The experimental area is located at the geographic coordinates 18°46′24″ S and 52°37′25″ W (Datum WGS-84), with an altitude of 820 m (Figure 1). The climate is classified as humid tropical according to the Köppen classification (Cunha, Magalhães, & Castro, 2013).

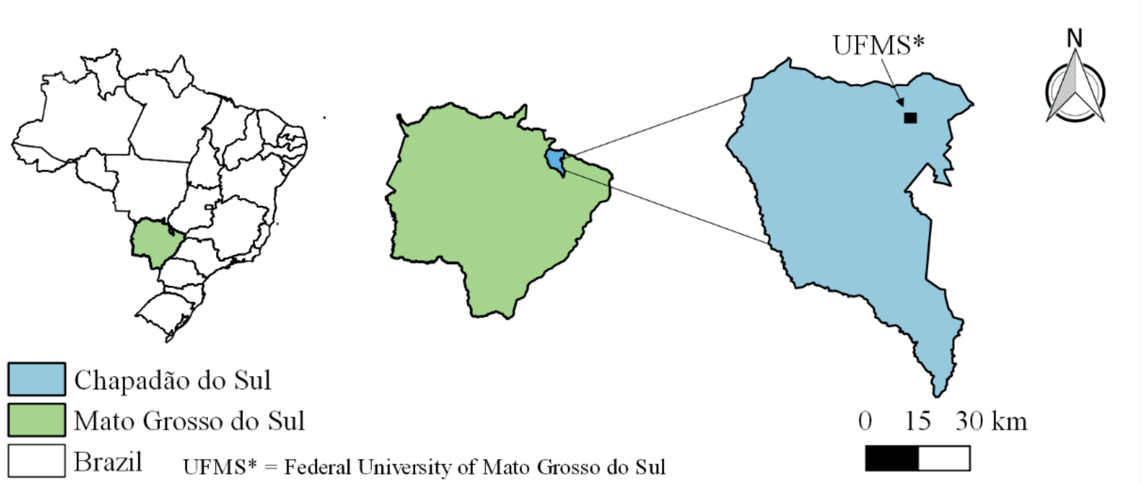

Figure 1. Location of the municipality of Chapadão do Sul relative to the state of Mato Grosso do Sul and Brazil.

Experimental design

The experiment was conducted in a randomized block design, in a split-plot scheme, with four irrigation frequencies in the plots and five vermiculite proportions in the subplots, arranged in six blocks. Sampling units consisted of six seedlings.

Four irrigation frequencies were evaluated: daily irrigation (11:00 a.m.), two daily irrigations (11:00 a.m. and 7:00 p.m.), three daily irrigations (7:00 a.m., 11:00 a.m., and 7:00 p.m.), and four daily irrigations (07:00 a.m., 11:00 a.m., 3:00 p.m., and 7:00 p.m.).

The daily amount of water applied in all treatments met 200% of the reference evapotranspiration (ETo) that occurred the previous day, that is, irrigation management was established with the crop coefficient (Kc) = 2. The amounts of water applied in the treatments were divided according to the number of daily irrigations. Irrigations were performed manually using watering cans, which were filled with known volumes of water measured using beakers.

Vermiculite proportions for the substrates used in the experiment consisted of 0, 25, 50, 75, and 100%. The 25% treatment, for example, used 25% vermiculite and 75% soil, with a 1:3 ratio.

Weather data and calculation of reference evapotranspiration (ETo)

The weather data were obtained from a Vaisala MAWS301 (Vaisala HydroMet™, Finland) automatic weather station, equipped with the following sensors: pyranograph, barometer, thermograph, hygrograph, pluviograph, and anemograph. These data allowed calculating ETo using the Penman-Monteith model (Allen, Pereira, Raes, & Smith, 1998), according to Equation 1.

$$ETo = \frac{0.408\, s\,(R_n - G) + \gamma \frac{900}{T+273} U_2 \frac{(e_S - e)}{10}}{s + \gamma\,(1 + 0.34\, U_2)} \qquad (1)$$

where ETo is the reference evapotranspiration (mm day^{-1}), s is the slope of the saturation pressure curve (kPa °C^{-1}); R_n is the radiation balance (MJ m^{-2} day^{-1}), G is the soil heat flow (MJ m^{-2} day^{-1}), γ is the psychrometric constant (kPa °C^{-1}), t is the mean air temperature (°C), U_2 is the wind speed at 2 m high (m s^{-1}), e_S is the water vapor saturation pressure (hPa), and e is the current water vapor pressure (hPa).

Variations in weather elements that occurred during the experimental period are shown in Figure 2.

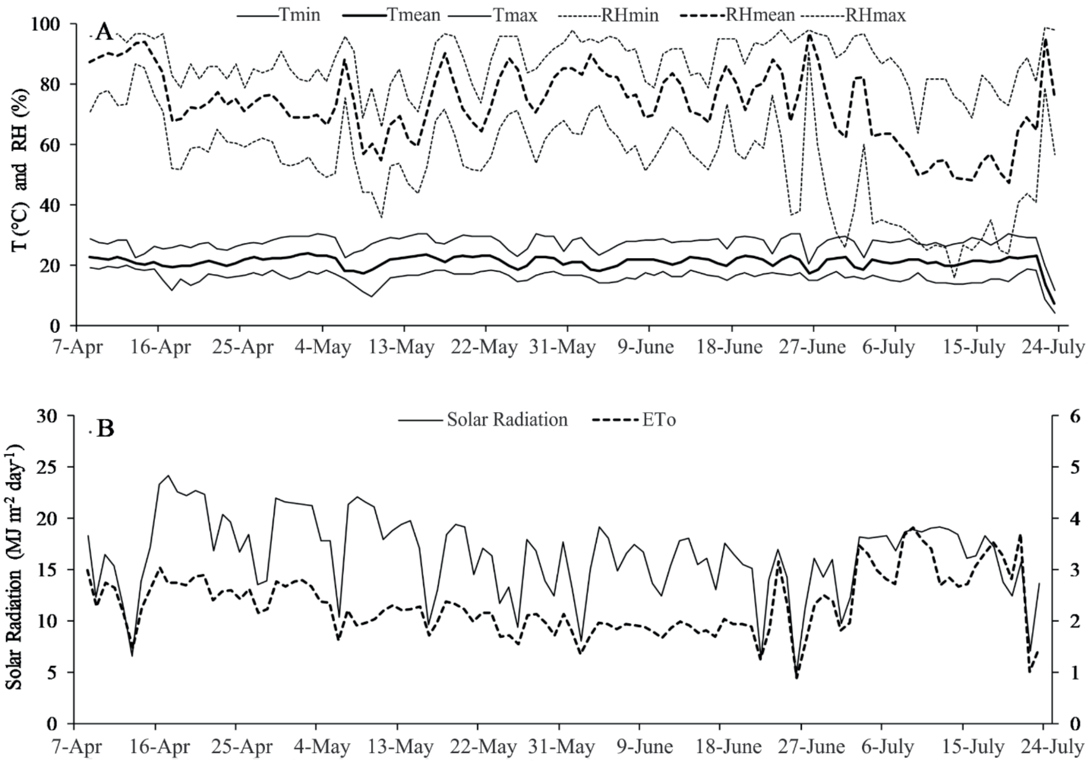

Figure 2. Daily variation of (A) minimum (Tmin), mean (Tmean), and maximum air temperature (Tmax), minimum (RHmin), mean (RHmean), and maximum relative air humidity (RHmax), and (B) solar radiation and reference evapotranspiration (ETo) during the experimental period from April 8 to July 23, 2013. Chapadão do Sul, MS, Brazil.

Container, substrate, and seedlings

Conical tubes with a 50-cm^3 volumetric capacity were filled with vermiculite (medium granulometry) and soil passed through a 2-mm opening sieve. Vermiculite proportion varied according to the subplots, with values of 0, 25, 50, 75, and 100% (mentioned in the experimental design section). Vermiculite is a substrate commonly used for forest seedling production, showing characteristics that favor plant growth (Martins, Machado, Caldas, & Vieira, 2011). The used vermiculite had a water retention capacity of 50%.

Seeds of the species *Eucalyptus grandis* were purchased from the company MP Florestal, and their sowing was carried out after filling the tubes. A density consisted of three seeds per tube. After sowing, the tubes were placed in suspended trays and conducted in a nursery covered by a 50% shading polypropylene screen, as recommended by Dutra et al. (2015). Thinning was carried out at 45 days after germination to maintain only one plant per tube.

Evaluation of treatments

The following seedling characteristics were analyzed: number of definitive leaves of *E. grandis*; plant height from the collar, in centimeters, measured using a millimeter ruler; number of surviving seedlings, converted to percentage; and total, shoot, and root dry mass.

Subsequently, the seedlings were cut at the collar region and separated into shoot and root. The root was washed in 1-mm mesh metal trays to remove the substrate. Both plant parts were packed in paper bags previously identified according to each treatment and maintained in a forced-air circulation oven (65±3 °C) until constant weight to obtain the shoot, root, and total dry mass.

The seedling quality index (DQI) was calculated using the Dickson's methodology (Dickson, Leaf, & Hosner, 1960), according to Equation 2:

$$DQI= \frac{TDM}{\frac{PH}{PD}+\frac{SDM}{RDM}} \quad (2)$$

where DQI is the Dickson seedling quality index, TDM is the total dry mass (g/plant), PH is the plant height (cm), PD is the plant diameter (mm), SDM is the shoot dry mass (g/plant), and RDM is the root dry mass (g/plant).

Water use efficiency (WUE, kg m^{-3}) was obtained by the relationship between the total dry mass of eucalyptus seedlings and the amount of water applied at each plot.

The data were submitted to the analyses of variance and regression. The comparison of means was performed using the Tukey test at a 5% probability. Linear and quadratic models were tested for quantitative factors. The model was selected based on the significance of the regression coefficients, using the t-test at a 5% probability, coefficient of determination (R^2), and biological phenomenon. The experimental package Designs was used in software R to perform the statistical analyses.

Results and Discussion

Treatments received the volume of 552.6 L of water per square meter of tray throughout the experimental period, resulting in a mean daily water depth of 5.5 mm. However, this value cannot be recommended for the irrigation of eucalyptus seedlings of other regions or periods different from those used in the present study, as these values were taken from the study of the regional evapotranspiration demand. Because the present study aims to meet a regional seedling production demand focused on poorly technified nurseries, we do not consider this factor a limitation. Seedling production in the least technified nurseries of the region is usually conducted during the period in which the present study was carried out.

Water demand of eucalyptus seedlings varies abruptly according to local climate conditions and, therefore, it is important to emphasize the scope of this study. Silva et al. (2015) irrigated seedlings from different eucalyptus hybrids in the summer of Viçosa, MG, Brazil, and found that the best daily irrigation depth was 11 mm, while Queiroz et al. (2017) found a value of 4.5 mm for Montes Claros, MG, Brazil.

The interaction between irrigation frequencies and vermiculite proportions in the substrate was significant for all the studied factors (Table 1). The slicing of the interaction for the number of final leaves of eucalyptus seedlings showed that the treatment consisting of 75% vermiculite and 25% soil and daily irrigation frequency provided the lowest value compared to the other frequencies. However, the other vermiculite proportions showed no differences between irrigation frequencies (Table 2).

Table 1
Analysis of variance for the number of definitive leaves (DL), plant height (PH), shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM), seedling quality index (DQI), survival (S), and water use efficiency (WUE) of eucalyptus seedlings

Source of variation	DF	Average square							
		DL	PH	SDM	RDM	TDM	DQI	S	WUE
Block	5	2.1E+1**	1.9E+1*	2.5E+0*	1.6E-1*	2.9E+0ns	6.0E-3ns	1.1E+3**	5.8E+0ns
IF	3	1.0E+1*	1.1E+2**	2.2E+1**	1.1E+0**	3.3E+1**	8.9E-2**	5.4E+2*	6.7E+1**
Residual (a)	15	2.8E+0	4.8E+0	7.7E-1	4.8E-2	1.1E+0	2.9E-3	1.4E+2	2.2E+0
VS	4	3.6E+2**	3.4E+2**	4.3E+1**	1.4E+0**	6.0E+1**	1.8E-1**	2.1E+4**	1.2E+2**
IF×VS	12	1.1E+1**	1.7E+1**	2.8E+0**	1.2E-1**	3.9E+0**	1.1E-2**	7.4E+2**	7.9E+0**
Residual (b)	80	3.2E+0	2.8E+0	4.1E-1	1.9E-2	5.1E-1	1.7E-3	1.7E+2	1.0E+0
Total	119	1.7E+1	1.9E+1	2.8E+0	1.1E-1	3.9E+0	1.1E-2	9.8E+2	7.8E+0
CV(%) plot		20.49	32.32	43.85	56.49	43.44	32.42	17.73	43.44
CV(%) subplot		22.10	24.83	32.13	35.39	29.27	24.68	19.14	29.97

IF = irrigation frequency; VS = vermiculite substrate; DF = Degrees of Freedom; * p<0.05; ** p<0.01; ns not significant.

Definitive leaves are related to seedling development, and irrigation frequency showed no effect on this attribute (Table 2). The number of leaves is important because the energy for the plant is produced in their photosynthetic surface (F. B. Martins & Streck, 2007).

Vermiculite proportions provided a quadratic effect on the number of final leaves of eucalyptus seedlings (Figure 3). The regression equations showed that vermiculite proportions of 84, 78, 74, and 79% in the substrate maximized the final number of leaves in eucalyptus seedlings for irrigation frequencies of 1, 2, 3, and 4 times a day, resulting in values of 10.3, 12.2, 11.3, and 11.3 leaves per plant, respectively (Figure 3). Possibly, vermiculite proportions between 74 and 84% for the substrate constitution provided the best physicochemical properties, essential characteristics for seedling quality according to Ehlers and Arruda (2014), Kratz and Wendling (2016), and Navroski et al. (2016).

Table 2
Mean values of the number of definitive leaves, plant height, shoot dry mass, root dry mass, total dry mass, seedling quality index, survival, and water use efficiency of eucalyptus seedlings for different irrigation frequencies and vermiculite proportions in the substrate

Response	Substrate vermiculite proportion	Irrigation frequency							
		1x a day		2x a day		3x a day		4x a day	
Definitive leaves (n°/plant)	0%	2.153	a	2.778	a	1.319	a	2.843	a
	25%	7.375	a	6.597	a	4.583	a	5.813	a
	50%	10.625	a	10.667	a	11.125	a	11.431	a
	75%	7.486	b	13.639	a	11.625	a	10.986	a
	100%	11.181	a	10.764	a	9.514	a	10.625	a
Plant height (cm)	0%	0.958	a	1.329	a	0.646	a	1.047	a
	25%	4.486	ab	5.257	ab	6.283	a	3.282	b
	50%	8.093	b	14.328	a	8.915	b	6.931	b
	75%	6.219	c	13.871	a	9.989	b	6.458	c
	100%	9.165	b	11.944	a	9.096	b	6.608	b
Shoot dry mass (g/plant)	0%	0.086	a	0.346	a	0.366	a	0.097	a
	25%	0.893	ab	1.852	a	0.491	b	0.957	ab
	50%	1.966	b	3.522	a	3.373	a	1.138	b
	75%	2.356	c	5.448	a	4.224	b	2.164	c
	100%	2.011	b	4.132	a	3.092	a	1.511	b
Root dry mass (g/plant)	0%	0.016	a	0.050	a	0.061	a	0.019	a
	25%	0.155	a	0.353	a	0.290	a	0.157	a
	50%	0.306	b	0.724	a	0.636	a	0.255	b
	75%	0.432	bc	1.144	a	0.639	b	0.323	c
	100%	0.390	b	0.878	a	0.652	a	0.278	b
Total dry mass (g/plant)	0%	0.103	a	0.395	a	0.427	a	0.116	a
	25%	1.048	ab	2.191	a	0.780	b	1.115	ab
	50%	2.271	b	4.247	a	4.009	a	1.393	b
	75%	2.788	c	6.637	a	4.863	b	2.488	c
	100%	2.401	c	5.009	a	3.744	b	1.789	c
Seedling quality index	0%	0.021	a	0.046	a	0.062	a	0.017	a
	25%	0.089	b	0.213	a	0.086	b	0.124	b
	50%	0.135	b	0.216	a	0.274	a	0.115	b
	75%	0.216	c	0.359	a	0.286	b	0.180	c
	100%	0.155	b	0.299	a	0.268	a	0.143	b
Seedling survival (%)	0%	20.83	a	30.56	a	13.89	a	24.93	a
	25%	71.53	a	41.67	b	52.50	ab	38.33	b
	50%	80.56	a	87.50	a	90.28	a	84.03	a
	75%	63.89	c	99.31	a	90.28	ab	75.83	bc
	100%	97.22	a	98.61	a	96.53	a	84.03	b

continue

continuation

Water use efficiency ($g\ L^{-1}$)	0%	0.145	a	0.560	a	0.606	a	0.164	a
	25%	1.487	ab	3.107	a	1.106	b	1.581	ab
	50%	3.221	b	6.022	a	5.685	a	1.975	b
	75%	3.954	c	9.412	a	6.897	b	3.528	c
	100%	3.404	c	7.104	a	5.310	b	2.537	c

Means followed by the same letter in the row do not differ statistically from each other by the Tukey test (p<0.05).

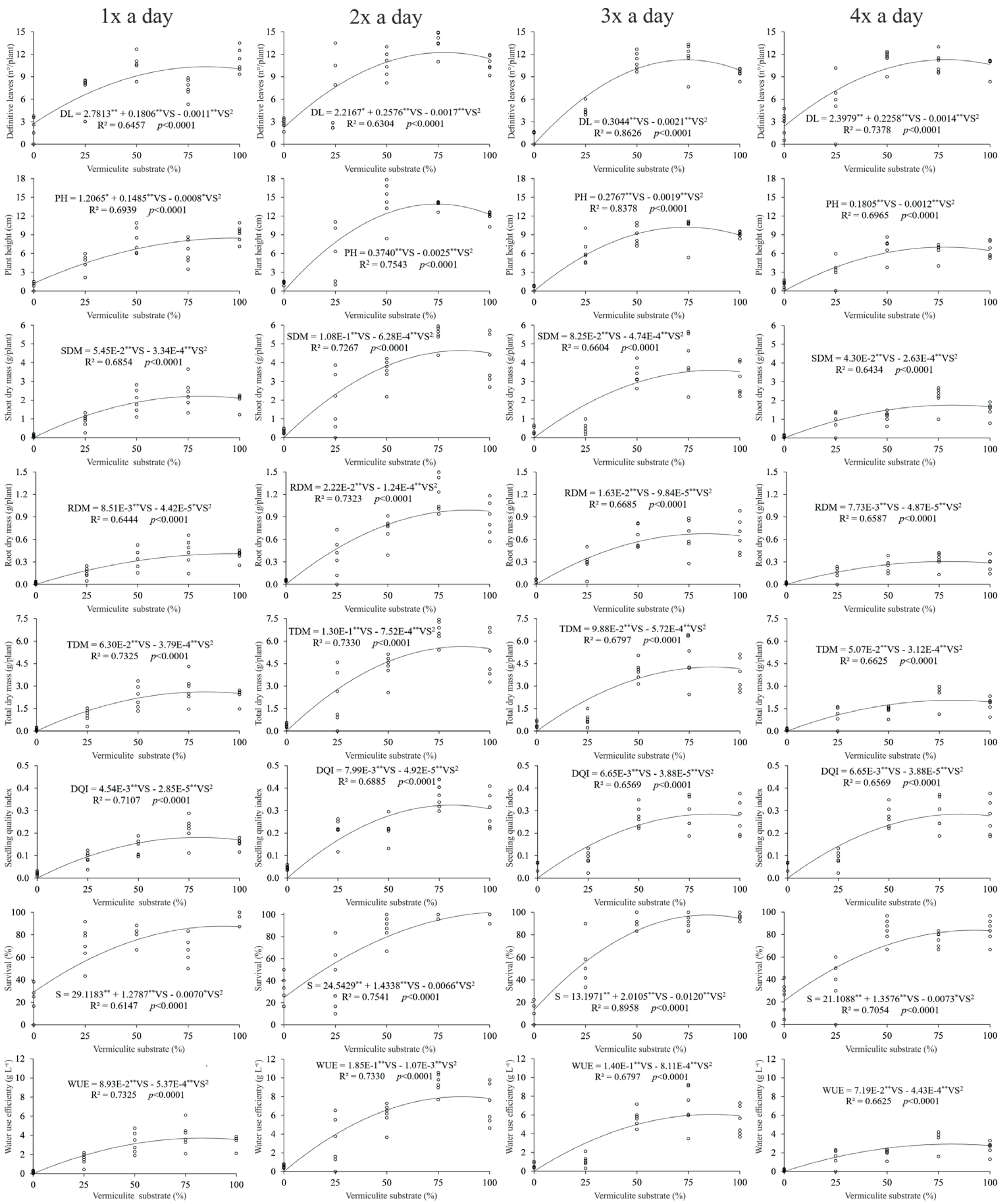

Figure 3. Estimation of the number of definitive leaves (DL), plant height (PH), shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM), seedling quality index (DQI), survival (S), and water use efficiency (WUE) of eucalyptus seedlings as a function of vermiculite proportions in the substrate (VS).

The treatment with two daily irrigations always showed the highest values of plant height regardless of the vermiculite proportion of the substrate used in the eucalyptus seedling (Table 2). Also, only the treatment with soil alone (0%) showed no difference between irrigation frequencies. It possibly occurred because the limitation of nutrients and high soil density are more restrictive than the supply of water via irrigation. However, producing seedlings in 50-cm^3 tubes without fertilizing can be harmful to their physiological quality.

Vermiculite proportions provided a quadratic effect on the plant height of eucalyptus seedlings (Figure 3). The regression equations showed that vermiculite proportions of 97, 74, 74, and 78% maximized the plant height for irrigation frequencies of 1, 2, 3, and 4 times a day, resulting in values of 8.5, 13.9, 10.2, and 7.0 cm, respectively (Figure 3). The treatment that received only daily irrigation required the highest vermiculite proportion in the substrate to maximize its plant height. This behavior was possibly due to the need for high water retention, as only one daily irrigation was performed.

Table 2 shows that the treatment with two daily irrigations always had high values of the shoot, root, and total dry mass and seedling quality indices, regardless of the vermiculite proportion in the substrate used in the eucalyptus seedling. This result is similar to the other factors mentioned above and due to the high correlation between them, as shown in Table 3.

Table 3

Pearson's correlation for the variables number of definitive leaves (DL), plant height (PH), shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM), seedling quality index (DQI), survival (S), and water use efficiency (WUE) of eucalyptus seedlings

	DF	PH	SDM	RDM	TDM	S	DQI
PH	0.8488**						
SDM	0.7636**	0.8664**					
RDM	0.7073**	0.8690**	0.9503**				
TDM	0.7590**	0.8729**	0.9986**	0.9654**			
S	0.9283**	0.8741**	0.7537**	0.7360**	0.7560**		
DQI	0.6856**	0.7565**	0.9319**	0.9257**	0.9374**	0.6957**	
WUE	0.7590**	0.8729**	0.9986**	0.9654**	1.0000**	0.7560**	0.9374**

**$p<0.01$. Correlation (r) classification according to Cohen (1988), very low ($r < 0.1$); low ($0.1 < r < 0.3$); moderate ($0.3 < r < 0.5$); high ($0.5 < r < 0.7$); very high ($0.7 < r < 0.9$); and almost perfect ($r > 0.9$).

The treatment with only one irrigation showed worse results, possibly because the soil-substrate set does not retain all the water applied and necessary for the plant. According to Felippe et al. (2016), substrates have a maximum capacity to retain water close to 58%. However, Tatagiba et al. (2015) found that 70% of this maximum water retention capacity is what provides the best performance of eucalyptus seedlings when using a vermiculite substrate. Moreover, the present study showed only a difference in irrigation fractionation, but all treatments received the same irrigation depth. The possible explanation for the low performance in the treatment with four daily irrigations is possibly related to the loss of water retained in the leaves. This treatment, despite the high frequency, received the application of low irrigation depths. According to Allen et al. (1998), vegetation cover is responsible for retaining the equivalent of up to 20% of the reference evapotranspiration (ETo) per rainfall or irrigation event. Thus, considering a mean ETo of 2.5 mm day^{-1}, it is estimated a loss of up to 2 mm of irrigation depth (2 L of water for each square meter of tray) in this treatment, which was retained in the leaves and did not reach the tubes with the soil-substrate set. In addition, this amount of water was considered a loss because of its evaporation by the leaf surface, not being used by the plant in any metabolic process.

Table 2 also shows that treatment with three daily irrigations often provided the same results as treatment with two daily irrigations. However, it is recommended for less-technified producers of eucalyptus seedlings to manage with two daily irrigations (11:00 a.m. and 7:00 p.m.), as labor will be saved compared to the management with three applications. Freitag et al. (2012) applied the same treatments to the production of *Pinus elliottii* seedlings in Santa Maria, RS, Brazil, and concluded that frequencies of three daily irrigations would be more suitable to produce physiologically better seedlings, with lower water costs during the production process. However, the species studied by Freitag et al. (2012) is more demanding for water in relation to *E. grandis*. Also, it is necessary to carry out other tests with the same irrigation frequencies during the day and using the same methodology to estimate the need for water already used in this experiment, but with different application times, in order to reach the maximum level development of eucalyptus seedlings in a nursery.

The recommendation for a frequency of two daily irrigations can also be reinforced by the better performance observed for the parameter root dry mass (Table 2). Mendonça et al. (2016) reported that the more abundant the root system, the greater the chance of seedling survival in the field regardless of the shoot height, with the root dry mass being an important indicator of seedling quality, as it is related to survival and initial growth in the field. In this sense, the highest root dry mass of seedlings produced under treatment with a frequency of two daily irrigations is evidence of the potential of this water management for eucalyptus seedling production. Higher root production can also provide higher substrate stability and, consequently, better-quality seedlings.

Vermiculite proportions for substrate composition also provided a quadratic effect on the shoot and root dry mass of eucalyptus seedlings (Figure 3). On average, the approximate vermiculite proportion of 80% maximized the dry biomass. Therefore, producers of *E. grandis* seedling are recommended to fill tubes with substrate containing 80% vermiculite and 20% soil or follow a volumetric ratio of 1:4 (soil: vermiculite).

The seedling quality index (DQI) proposed by Dickson et al. (1960) is an important weighted morphological measure. It is a good indicator of seedling quality, as it considers the robustness and balance of seedling biomass distribution for its calculation (Cerqueira, Azevedo, Souza, & Azevedo, 2017; R. F. Silva, Marco, Ros, Almeida, & Antoniolli, 2017). The higher the DQI value, the better the quality of a seedling, but Cerqueira et al. (2017) reported that good quality seedlings have DQI values above 0.20. Thus, only eucalyptus seedlings that received vermiculite proportions higher than 50% (Figure 3) and frequencies of two or three daily irrigation (Table 2) can be considered of quality.

High adaptive plasticity of eucalyptus seedlings to different irrigation frequencies was observed relative to survival, as no treatment stood out (Table 2). However, vermiculite proportion in the substrate is essential for high seedling survival, as shown in Figure 3. On average, the approximate vermiculite proportion of 92% maximized eucalyptus seedling survival. Vermiculite proportions of up to 25% in the substrate resulted in a 50% mortality of eucalyptus seedlings.

As in the other analyzed variables, the frequency of two daily irrigations (Table 2) and vermiculite proportions of 80% (Figure 3) provided higher values of water use efficiency (WUE) for eucalyptus seedlings. The mean WUE value was 3.39 g L^{-1}, considering all treatments. This result indicates that 295 L of irrigation water are required to produce 1 kg of dry biomass of eucalyptus at the seedling stage.

Conclusions

Water management with two daily irrigations (11:00 a.m. and 7:00 p.m.) is recommended in less technical nurseries for the production of *Eucalyptus grandis* seedlings.

The filling of tubes must be carried out with a substrate consisting of 80% vermiculite and 20% soil, following a volumetric ratio of 1:4 (soil: vermiculite).

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