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ORIGINAL ARTICLE – Forest Management

Effect of Localized Irrigation on Dendrometric Attributes of *Eucalyptus* Hybrids

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Abstract

This study aimed to evaluate the influence of drip irrigation and micro-sprinkler on the dendrometric parameters of two *Eucalyptus* hybrids at 45 months. The experiment was carried out in Aquidauana, MS, using an experimental design of randomized blocks in split plot scheme. The dendrometric attributes of the trees evaluated were height, diameter at breast height, volume, shape factor, taper, and dry mass production. The Grancam hybrid has the highest growth in height, and the Urograndis has the largest diameter at breast height. Drip irrigation provides an increase of 36.7% in the wood volume of eucalyptus hybrids when compared to those that were not irrigated.

Keywords: taper, form quotient, drip irrigation, micro-sprinkler, wood volume.

1. INTRODUCTION AND OBJECTIVES

Forests in Brazil have been increasing fast, especially in the case of eucalyptus plantations, which represent 72.7% of the total planted forests (Ibá, 2017). Eucalyptus is an exotic genus originating in Australia (Miranda et al., 2015) and its high growth rate, its adaptive plasticity to different edaphoclimatic conditions, and the multiple uses of its wood are the causes of its preference in commercial plantations. Another relevant factor is the genetic improvement that, combined with management and silvicultural techniques, allows the use of this genus in different regions of the country (Paula et al., 2012).

Due to the rapid expansion of the planted tree sector, more information is needed on how the water used by these plantations influences dendrometric parameters, and thus forest productivity, in order to understand the balance between productivity gain and water resource conservation (Li et al., 2019). This is important especially for plantations of species of the genus *Eucalyptus*, which have higher water consumption and faster growth than most native species (Amazonas et al., 2018).

Water plays a fundamental role in physiological plant processes (Taiz & Zeiger, 2017). Plants under water deficit are negatively affected, resulting in loss of turgidity, stomatal closure and altering the rate of transpiration and photosynthesis (Dombroski et al., 2014). These factors can lead to reduced plant development and, consequently, to a loss of productivity (Mitchell & O'Grady, 2015; Taiz & Zeiger, 2013).

With growing concern regarding water scarcity and its conscious use, coupled with the increased demand for products from eucalyptus plantations, techniques that promote forest productivity without the inappropriate use of this resource have become necessary. These techniques include genetic improvement and irrigation. Irrigation management aims to provide sufficiently controlled water at the right time (Kruashvili et al., 2016), complementing rainfall and avoiding waste of water.

Some studies have shown the importance of water in forestry, such as Bernardino et al. (2019). These authors concluded that increasing the irrigation depth also increases the survival of eucalyptus seedlings during their growing period and provides greater seedling development. While evaluating the growth

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potential of eucalyptus forests with different nutrient and water supplies, Stape et al. (2010) obtained an average increase of 30% in productivity in irrigated treatments. Reis et al. (2006), while evaluating the field growth of eucalyptus hybrids, found higher wood volume values in irrigated treatments when compared to non-irrigated treatments, demonstrating that irrigation can be a tool for increasing forest productivity.

Thus, it is evident that irrigation can provide changes in the biometric properties of eucalyptus plantations. In this context, the objective of this study was to evaluate the influence of localized irrigation on the dendrometric parameters of the eucalyptus hybrids Urograndis and Grancam at 45 months.

2. MATERIALS AND METHODS

The study was conducted in the experimental irrigation area of the State University of Mato Grosso do Sul, Campus of Aquidauana (UEMS/UUA), with the following geographic coordinates: 20° 27' S, 55° 39' W and an average altitude of 207 meters. The climate of the region, according to the Köppen classification, belongs to the subtype Aw, warm tropical, sub-humid, with average annual rainfall[I] of 1286 mm. The soil was identified as a dystrophic Red Argisol with a sandy texture by Schiavo et al. (2010).

The experimental area consisted of 3 hectares (ha): 1 ha for each irrigation system (drip and micro-sprinkler) and 1 ha without irrigation. The planting was carried out in April 2011 using two eucalyptus hybrids: Urograndis, clone AEC 224 (*Eucalyptus urophylla* × *E. grandis*) and Grancam, clone 1277 (*Eucalyptus grandis* × *E. camaldulensis*), with seedlings spaced at 2.25 × 4.00 m.

The experimental design used was randomized blocks in split plot scheme, using four blocks and two replications within each block. The plots corresponded to two irrigation systems, micro-sprinkler and drip, and a control treatment, without irrigation. The subplots were the eucalyptus hybrids Urograndis and Grancam, and each subplot was composed of 10 plants (90 m^2), with an 8 m distance from each other.

The climatic data were obtained through the weather station of the Instituto Nacional de Meteorologia (INMET) in the municipality of Aquidauana, MS, until the 29th of the month after planting (MAP) and subsequently through the weather station installed at the Campus of Aquidauana, consisting of daily temperature data (maximum and minimum), relative humidity, global solar radiation, wind speed and rainfall until January 2015 (45 months after planting) (Figure 1).

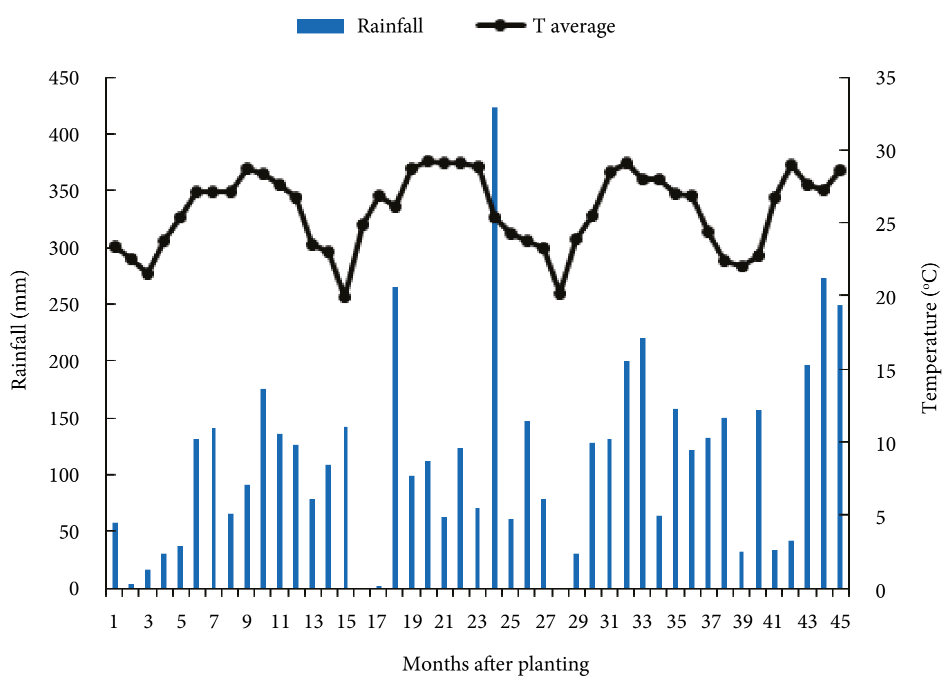

Figure 1. Monthly average rainfall and temperature data.

[I] Average rainfall calculated from 2007 to 2015. Data collected from: https://bit.ly/32RTWOA

For localized irrigation, micro-sprinkler with 48 L h^{-1} unit flow, 1.5 m range and 40 m c.a. installed at 0.3 m from each plant and self-compensating drippers, with 2.4 L h^{-1} flow and 0.5 m spacing between emitters, with a working pressure of 10 m c.a were used.

Irrigation management was based on the estimation of reference evapotranspiration from the Penman-Monteith equation (Allen et al., 1998). Crop evapotranspiration (ETc) was estimated with adaptations for localized irrigation (Bernardo et al., 2006), using the crop coefficient of 0.82 for eucalyptus (Alves et al., 2013) and a correction factor according to the localized irrigation method (Keller & Bliesner, 1990). The percentage of wet area was calculated according to Bernardo et al. (2006).

Micro-sprinkler and drip irrigation systems resulted in 75% and 25% of wet areas, respectively. Readily available water (RAW_{loc}) was used as a criterion for the calculation of the irrigation depth. The depth of the root system was 970 mm (Reis et al., 2006) and the soil water depletion factor for conifers of 0.7, as recommended by Allen et al. (1998).

The RAW_{loc} was 31.1 and 93.3 mm for drip and micro-sprinkler, respectively. However, irrigation was performed whenever the sum of ETc was equal to or greater than 9 mm, due to the high frequency and low intensity of water application, characteristic of localized irrigation.

The total irrigation depth (TID) of the implantation period up to 45° MAP for the micro-sprinkler system was 9.1% higher when compared to the drip system and 29.7% larger than the area without irrigation. The drip system provided an 18.9% higher TID compared to the non-irrigated area (Table 1).

The dendrometric attributes evaluated were plant height (H), with the aid of a digital clinometer; circumference at breast height (CBH at 1.3 m height) using tape measure and subsequently converted to diameter at breast height (DBH at 1.3 m height). The wood volume (V) was obtained by rigorous cubing of 40 selected trees in the sample units based on the diameter at the average breast height of the subplots, in which the tree closest to this value was chosen. The cubing was performed according to the Hohenadl method (Machado & Figueiredo Filho, 2009), with section lengths established in relation to the total height and circumferences measured at 10%, 30%, 50%, 70% and 90% of the total height, thus calculating the total volume of the individuals. For calculating the average wood volume per hectare, the wood volume obtained by treatment was multiplied by the number of plants per hectare (1111 individuals).

Form quotient (fq) was obtained according to Equation 1 and the taper of trees (T) by Equation 2, adapted from Vital (2008).

$$fq = \frac{Vsol}{Vc} \qquad (1)$$

Where:
Fq: form quotient;
Vsol: solid volume (rigorous cubing);
Vc: cylinder volume.

$$T = \frac{\left(\frac{d1+d2}{2}\right) - \left(\frac{d3+d4}{2}\right)}{L} \qquad (2)$$

Where:
T: taper (%);
d1 and d2: diameters of the thickest end of the log (cm);
d3 and d4: diameters of the thinnest end of the log (cm);
L: log length (m).

Dry mass yield of irrigated and non-irrigated eucalyptus hybrids (control treatment) was also evaluated. To calculate the dry mass, the basic wood density (D_b) obtained by Benites et al. (2018) was considered for the same treatments as the experimental planting under study.

The results were submitted to the analysis of variance and to Tukey's test, at 5% significance.

3. RESULTS AND DISCUSSION

There was no significant interaction between the analyzed factors (irrigation systems × eucalyptus hybrids). Localized irrigation (micro-sprinkler and drip) provided higher growth of plants in height when compared to non-irrigated plants ($p < 0.05$), being the major influence provided by the drip system (Table 2). Thus, it is likely that the highest growth in irrigated eucalyptus clones is due to higher water availability, reflecting higher transpiration, stomatal conductance and photosynthesis rates (Fernandes et al., 2015).

Table 1. Irrigation depth applied and total length of the implantation period up to 45° MAP.

	TID (mm)	Precipitation (mm)	ID (mm)
MIC	1527.92	5149.27	6677.19
DRIP	973.57	5149.27	6122.84
CT	–	5149.27	5149.27

ID: irrigation depth; TID: total irrigation depth; MIC: micro-sprinkler; CT: control treatment.

Studies carried out with eucalyptus species show that growth parameters decreased due to soil water deficit (Martins et al., 2008; Stape et al., 2004). Similar results were found for other forest species such as *Corymbia citriodora* (Abreu et al., 2015), *Libidibia ferrea* and *Poincianella bracteosa* occurring in seasonally dry tropical forests (Ferreira et al., 2015).

Plants under water stress tend to partial stomatal closure (Mugunga et al., 2015; Taiz & Zeiger, 2013). They seek to minimize water loss through perspiration (Souza et al., 2014), thus altering gas exchange patterns, limiting the availability of CO_2 within the mesophyll and reducing the rate of photosynthesis (Scalon et al., 2011), as obtained by Spokevicius et al. (2017), who found stomatal conductance and reduced sub-stomatal carbon concentration in drought conditions.

Eucalyptus hybrids also showed a significant difference ($p < 0.05$) in relation to height, with a higher value for the Grancam hybrid. This trend of higher growth in height presented at 45 months by the hybrid Grancam has been verified since its initial development (7 to 17 months) (Jung et al., 2017). It may be related to a better interaction of the genotype with the environment, which allowed its higher growth.

DBH did not differ ($p > 0.05$) between irrigated and non-irrigated trees (Table 2). This may be due to the lower water availability for non-irrigated plants. This condition may change the ethylene levels, which in turn confers a reduction in auxin transport and the redistribution of cellulose microtubules and microfibrils to a longitudinal position, causing significant lateral expansion (stem thickening) and consequent reduction in height (Ishihara et al., 2017; Taiz et al., 2017). Although no statistical difference was found for this variable, a higher DBH trend can be observed in irrigated trees.

However, DBH was influenced by genetic material ($p > 0.05$), the higher value being provided by Urograndis (Table 2). This may be related to the crossing of species, which results in characteristics of good silvicultural development, conferred by *E. grandis* (Sansígolo & Ramos, 2011), besides the rusticity and good wood characteristic of *E. urophylla* (Mora & Garcia, 2000). In addition, this hybrid has high adaptability to different forest sites, greater productivity and better wood quality (Montanari et al., 2007).

Drip irrigation provided greater wood volume when compared to the control treatment (without irrigation) ($p > 0.05$), and when there is water limitation there is also a significant reduction in stomatal conductance (White et al., 2016) influencing the photosynthetic process. Because of this, it can be inferred that the greater availability of water in the soil provided by irrigation favors the development of eucalyptus (Paula et al., 2012).

Studies such as Reis et al. (2006), which concluded that hybrids of *E. grandis* × *E. urophylla* and *Eucalyptus camaldulensis* × *E.* spp. submitted to irrigation presented larger wood volume when compared to non-irrigated treatment, 38 months after planting, corroborate this result. Also, in a stand of *Eucalyptus tereticornis*, irrigation with sewage promoted an increase in wood volume (Minhas et al., 2015).

Irrigation has increased by 30% the wood volume in clonal eucalyptus plantations at eight locations in Brazil, and water supply is considered the main resource that determines plantation productivity levels in the country (Stape et al., 2010). In this sense, volumetric growth is positively related to water use and is therefore optimized by irrigation (White et al., 2016).

Table 2. Mean values of height (H), diameter at breast height (DBH), wood volume (V), form quotient (fq) and taper (T) for the treatments.

TREATMENTS	H	DBH	V	fq	T
	m	cm	m^3		%
Micro-sprinkler	17.57 B	13.59 A	0.124 AB	0.489 A	0.72 A
Drip	18.39 A	13.81 A	0.134 A	0.484 A	0.67 A
Control	15.74 C	12.29 A	0.098 B	0.516 A	0.76 A
CV (%)	2.83	10.00	19.64	8.13	13.98
MSD	0.64	1.72	0.03	0.05	0.13
Urograndis	16.48 b	13.69 a	0.123 a	0.501 a	0.77 a
Grancam	18.48 a	13.13 b	0.122 a	0.484 a	0.65 b
CV (%)	4.23	5.68	14.37	6.34	3.37
MSD	0.51	0.52	0.01	0.02	0.02

MSD: minimum significant difference; CV: coefficient of variation. Averages followed by the same letter in the columns do not differ statistically by Tukey's test at 5% significance level, uppercase letters represent irrigation systems and lowercase letters represent eucalyptus hybrids.

Among the eucalyptus hybrids, no significant difference ($p > 0.05$) was observed for wood volume. This fact may be related to the higher DBH value provided by the Urograndis hybrid and higher height value of the Grancam hybrid, thus compensating for the volume calculation, which considers these variables.

Fq was not influenced by irrigation and there was no significant difference between eucalyptus hybrids (Table 2) ($p > 0.05$) for this variable, despite being a factor influenced by genetic material (Campos & Leite, 2013), which may be related to hybridization, as they have *E. grandis* as a common species. Thus, the estimate form quotient found for the total tree volume was 0.501 for the hybrid Urograndis and 0.484 for the Grancam. Similar results were found for *Eucalyptus grandis*, with an average form quotient of 0.47, obtained for individual or stand volume calculation (Miguel et al., 2010).

The taper was not influenced by irrigation ($p > 0.05$) (Table 2), so the tree growth provided by the greater availability of water does not influence the shape of the stem. Furthermore, it was observed that eucalyptus hybrids provided a difference in taper ($p < 0.05$), and Urograndis presented a higher value. This can be explained by the fact that taper is a parameter that varies depending on the species (Vital, 2008).

The taper of the Urograndis and Grancam hybrids was 0.77% and 0.65%, respectively, and may be included in Class I, according to the standard for measurement and classification of hardwood logs, IBDF (1984), with taper values of less than 3% or 3 cm/m representing logs of higher quality class (Vital, 2008). Similar results were found in a study on the evaluation of the quality of logs and lumber of eucalyptus species, with the taper obtained at 0.86 cm/m (Hornburg et al., 2012).

When subjected to localized irrigation, the hybrids Urograndis and Grancam tended to increase the production of aerial dry biomass (Table 3). It is likely that non-irrigated plants prioritized the allocation of photoassimilates in the roots by stimulating their growth and lateral root formation to the detriment of aerial biomass production (Ryan et al., 2010; Taiz & Zeiger, 2013). Matos et al. (2016) found investment in the root system by the eucalyptus hybrid Urocan under the condition of significant water deficit.

Plants with low water availability tend to further explore the soil profile to increase water absorption potential (Taiz & Zeiger, 2013). Similar results were obtained in the research of Stape et al. (2004); Scalon et al. (2011); Maseda & Fernández (2016) and Fernández et al. (2018). The authors found higher values of shoot dry mass in plants under higher water availability.

Increased productivity of planted forests can lead to changes in wood quality (Sette Júnior et al., 2012). Thus, from all wood properties, density is one of the most important and can be changed with the use of some silvicultural treatments, such as spacing, irrigation and fertigation (Sousa et al., 2010). This was not verified for the hybrid Urograndis, which did not show a tendency to decrease in D_b with the use of irrigation, thus being considered more stable regarding water availability.

On the other hand, this change was verified in the Grancam hybrid when subjected to localized irrigation. This confirmed a reduction in D_b values, maybe due to greater hybrid availability, which stimulates the formation of larger diameter cells in response to activation of auxin growth hormone (Taiz et al., 2017).

Thus, it is recommended to use localized irrigation (micro-sprinkler and drip) to increase productivity in eucalyptus plantations, providing conditions for the genetic material to express its productive potential; and, in particular, the use of drip systems, which has an advantage over micro-sprinkler because it applies water more efficiently and closely to the roots, increasing volumetric production and allowing a reduction in the cutting time of crops.

Table 3. Dry mass production at 45 MAP of eucalyptus (Urograndis and Grancam) hybrids irrigated, drip and control treatments.

	TREATMENTS $m^3\ ha^{-1}$	V	TID	D_b*	Dry mass
		mm	$kg\ m^{-3}$	$kg\ ha^{-1}$	
Urograndis	Micro-sprinkler	131.73	6677.19	342	45052.47
	Drip	157.13	6122.84	384	60337.01
	Control	108.32	5149.27	351	38021.20
Grancam	Micro-sprinkler	142.84	6677.19	402	57422.64
	Drip	141.65	6122.84	384	54394.56
	Control	108.32	5149.27	451	48853.45

V: wood volume; TID: total irrigation depth; D_b: basic wood density.
*Data obtained from Benites et al. (2018).

4. CONCLUSIONS

Micro-sprinkler and drip irrigation allow a higher height growth of the Urograndis and Grancam hybrids.

The Grancam hybrid grows the most in height and the Urograndis in diameter at breast height.

Drip irrigation provides an increase of 36.7% in the wood volume of eucalyptus hybrids when compared to those that were not irrigated.

Form quotient and taper are not influenced by irrigation. Taper is only influenced by the type of genetic material used.

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