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Research Article
In-ground Irrigation and Fertirrigation Irrigation System in the Hybrid *Eucalyptus grancam*

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Abstract
As the demand for products from timberlands has been increasing, the genera Eucalyptus has highlighted for its yield potential and also due to its great adaptation to Brazilian soils, which are in general moderately acid. Therefore, the aim was to evaluate the growth of the hybrid *Eucalyptus grancam* under the, ground irrigation and fertirrigation irrigation system. The experiment was conducted in the experimental area of the University of the State of Mato Grosso do Sul, Campus of Aquidauana, Brazil. The experimental design was a randomized by blocks with split plots design, using four blocks and two replications within each block, where irrigation treatments (micro-sprinkler, drip irrigation and no irrigation area) were the main plots and the treatments of fertilization (fertirrigation and conventional fertilization) corresponded to the subplots. Measurements of plant height and diameter at breast height between 30° (1 October, 2013) and 41° (30 September, 2014) months after planting were made to estimate the stem volume per hectare. In response to these treatments, irrigation provides greater growth in height, diameter at breast height and stem volume of the hybrid, highlighting the micro-sprinkler system. The fertilizing irrigating system presents results similar to conventional fertilization. Thus, it can be an alternative when growing *Eucalyptus* spp., under in-ground irrigation systems.

Key words: Drip irrigation, *Eucalyptus* spp., fertilization, timberland, micro-sprinkler

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Brazil has shown considerable development in timberlands due to its great edaphoclimatic features and the technological development of the silviculture (Juvenal and Mattos, 2002).

As the demand for products from timberlands has been increasing, the genera Eucalyptus has highlighted for its yield potential and also due to its great adaptation to Brazilian soils, which are in general moderately acid.

According to Brazilian Association of Timberland Producers (ABRAF, 2013), over 76% (around 5 million ha) of Brazilian timberlands are covered by *Eucalyptus* spp., mostly hybrids, such as *E. grancam* (*E. grandis*× *E. camaldulensis*) and *E. urograndis* (*E. urophylla*× *E. grandis*).

The timberlands of Eucalyptus are widespread across Brazilian territory, where the majority is grown on degraded areas, under low soil fertility and long dry periods (Da Silva *et al*., 2004; Vellini *et al*., 2008).

In response to long periods of low rainfall, irrigation arises as an alternative when adequately managed and strictly suited to soil physical properties. This optimizes the amount of water used, preventing water loss by evaporation, percolation and runoff (Talamini and Oliveira, 2008).

During plant development only the necessary amount of water should be provided to have neither lack nor excess of water. Thus, there are three issues that have to be considered in irrigation management, such as: Timing, the necessary supply given on each application to match the culture needs and the rate of water consumed by the culture (Peiter *et al*., 1999).

To even enhance water use and its availability to plants, in-ground irrigation, such as micro-sprinkler and drip systems, appear as an alternative, where water is directly applied in the soil as close as possible of the roots. Despite small amounts of water supply is given in in-ground systems, irrigation frequency is often high in order to keep humidity easily reached by the roots, leaving the soil close to its field capacity (Mantovani *et al*., 2006).

In addition, fertilizers can also be applied with in-ground irrigation, forming a system called fertilizing irrigation. This system increases the efficiency in fertilizer applications as it provides favorable humidity conditions for nutrient uptake by the plants (Teixeira *et al*., 2007).

Thus, the overall aim of this study was to evaluate the growth of the hybrid *Eucalyptus grancam* under in-ground irrigation and fertilizing irrigation system as it is hoped that in-ground irrigation and fertilizing irrigation system will increase hybrid's volume increment when compared to the control treatment.

MATERIALS AND METHODS

The study was conducted at the experimental area of the University of the State of Mato Grosso do Sul (UEMS), Campus of Aquidauana, State of Mato Grosso do Sul, Brazil on the coordinates S 20°27'08" W 55°40'15" with an average elevation of 191 meters.

According to Köppen climate classification, the site climate is classified as Aw, a tropical savannah climate, where the summer is rainy while, the winter is dry, with an annual[1] rainfall average of 1231 mm. The site soil, according to Schiavo *et al*. (2010) was classified as a clay loam ultisol. The climate data was obtained from the campus meteorological station, where daily data of rainfall, temperature, relative humidity, overall solar radiation and wind speed, between 1st October, 2013 (30th month after planting) and 30th September, 2014 (41st month after planting) were collected (Fig. 1).

The hybrid *Eucalyptus grancam* (*E. grandis*× *E. camaldulensis*), clone 1277 was planted in 19th April, 2011, in a density of 1111 trees per hectare (laid 2.25 m between plants and 4 m between lines). The soil was fertilized following the recommendations of Andrade (2004) and also following the site's soil chemical analysis.

The experiment was arranged in 4 blocks, where plots were randomly placed into the blocks and repeated twice in each block (Banzatto and Kronka, 1989).

The treatments tested were plant growth under two systems of in-ground irrigation, micro-sprinkler and drip and plant growth without irrigation (control treatment). In the in-ground systems were also evaluated plant growth under conventional fertilization and under fertilizing irrigating system, while in the control treatment plants were grown only under conventional fertilization.

It was used drippers of 2.4 L ha^{-1} of water flow, distanced 0.5 m of each other and under a pressure of 10 m of water column. Also, micro-sprinklers, with water flow of 48 L ha^{-1}, radius range of 1.5 m and under a pressure of 40 m of water column were used, being each sprinkler set 0.3 m away from each plant.

The irrigation management was based in the Evapotranspiration Rate (ET) which was obtained from Penman-monteith equation (Allen *et al*., 1998). The culture evapotranspiration (ETc) was estimated with adaptations to in-ground irrigation by these following Eq.1 and 2:

$$\text{ETc} = \text{ETo kc} \quad (1)$$

where, kc is the culture coefficient, 0.82 for *Eucalyptus* spp., (Alves *et al*., 2013).

[1]Precipitation data obtained from 2007-2013, accessed in: http://www.inmet.gov.br/portal/index.php?r=estacoes/estacoesautomaticas

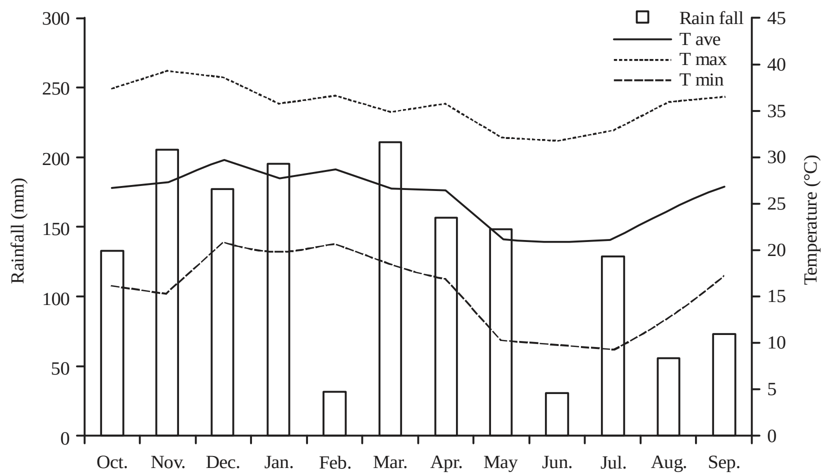

Fig. 1: Maximum, minimum and average of temperature and monthly rainfall in Aquidauana, Mato Grosso do Sul, Brazil, between October, 2013 (30°MAP) and September, 2014 (41°MAP)

$$\text{ETc in-ground} = \text{ETc kL} \tag{2}$$

where, kL is the correction factor according to in-ground irrigation method, estimated according to Eq. 3 by Keller and Bliesner (1990):

$$\text{kL} = 0.1\sqrt{\text{PWA}}\ (\%) \tag{3}$$

where, PWA is proportion of wetting area was calculated according to Mantovani *et al.* (2006).

In-ground irrigation systems, such as drip and micro-sprinkler, result in values of 25 and 75% of PWA, respectively. To calculate the volume of irrigation applied, Soil Water Availability (SWA) for in-ground irrigation was used as a parameter as it has been showed in the following Eq. 4:

$$\text{SWA in-ground} = (\theta\text{SFC}-\theta\text{PWP})\ \text{Z p PWA} \tag{4}$$

where, θSFC is soil moisture at soil field capacity (-10 kPa, $m^3\ m^{-3}$) and PWP is soil moisture at permanent wilting point (-1500 kPa, $m^3\ m^{-3}$). The Z is the depth of the root system, 970 mm according to Dos Reis *et al.* (2006) and p is soil's water depletion factor for conifers, 0.7 according to Allen *et al.* (1998).

The SWA was 31.1 and 93.3 mm for drip and micro-sprinkler systems, respectively. However, due to high frequency whereas low intensity of water applied, irrigation supply was run whenever the sum of ETc in-ground was greater or equals to 9 mm.

The site soil was conventionally fertilized and also fertilized by fertilizing irrigating system, applied in the 21st month after planting, being added 40 kg ha^{-1} of nitrogen (N), 20 kg ha^{-1} of potassium (K) and 3.3 kg ha^{-1} of boron (B) (Goncalves *et al.*, 2008). In the 32 nd month after planting the supply of K was once more given.

In the conventional fertilization, the fertilizers were applied directly in the soil within the canopy area of the trees, while in the fertilizing irrigating system, the fertilizers were watered and then applied with a fertilizer injection system named venturi.

The evaluation was made since the 30th month after planting (1st October, 2013) until the 41st month after planting (30th September, 2014), being measured Height (H) and Diameter at Breast Height (DBH) to estimate stem volume (V) of the trees as showed in the following Eq. 5:

$$V = h\ g\ 0.5 \tag{5}$$

where, V is the tree's stem volume m^3, h is the tree height (m) and g is the tree's transversal area, calculated by the following Eq. 6:

$$g = \frac{d^2\pi}{4} \tag{6}$$

where, d is obtained by tree's diameter at breast height divided by π. The value of 0.5 (Eq. 5) is a correction factor according to the standard shape of the *Eucalyptus* spp., stems (Boas *et al.*, 2009).

The data was statistically analyzed by analysis of variance (ANOVA). For treatments that presented significance on F-test, Tukey test was run to compare the means upon 95% of probability.

RESULTS AND DISCUSSION

The total of water provided (irrigation+precipitation) were 1647.6 mm in the treatments under micro-sprinkler irrigation and 1599.3 mm in treatments under drip irrigation, whilst trees on the control treatment grown under a precipitation of 1578.8 mm (Table 1). Furthermore, water applied by irrigation on both treatments provided a slight difference of 4.2 and 2.9%, respectively, in comparison to the control treatment.

The low amount of water applied, shown in Table 1 can be explained by the great rainfall distribution along the evaluation period, where only February, June, August and September presented rainfall rate below 100 mm monthly.

The evapotranspiration of the hybrid *E. grancam* (ETc in-ground) was 1021.1 mm under micro-sprinkler system, while it was 586.1 mm under drip system. This higher ETc under micro-sprinkler treatment is due to a greater wetting area reached by the sprinklers, which might end up increasing the amount of water loss by runoff and evaporation.

Table 2 shows that the hybrid *E. grancam* grown under irrigation supply presented considerable results when compared to trees cultured under control treatment. In relation to height, trees grown under no irrigation supply were a bit shorter, presenting a mean of 15.74 m, while trees grown under micro-sprinkler and drip systems presented a mean of 17.35 and 17.82 m, respectively.

According to the Table 2, although the control treatment presented the worst mean in height, it presented the best height increment along the measurement period, 4.06 m, which means 34.73 and 7.14% greater than micro-sprinkler and drip irrigation systems, respectively.

In time trees grown under no irrigation supply have a tendency to overcome water stress through root growth, where according to Tatagiba *et al.* (2007), plants use to maximize root growth downward the soil in response to water stress.

As a result of presenting great root development, the hybrid *E. grancam* can still respond with considerable yield

Table 1: Estimative of evapotranspiration for the hybrid *Eucalyptus grancam* under in-ground irrigation systems (ETc in-ground), showing the values of minimum, maximum, average, water applied by irrigation (WA) and total of water provided (TW), which considers precipitation, between the 30th month after planting (October, 2013) and the 41st month after planting (September, 2014) in Aquidauana, State of Mato Grosso do Sul, Brazil

	ETc in-ground					
	Maximum (mm dia^{-1})	Minimum (mm dia^{-1})	Average (mm dia^{-1})	Accumulated (mm)	WA	TW*
CT	-	-	-	-	-	1578.8
MIC	6.01	0.38	2.77	1012.1	88.8	1647.6
DRIP	3.47	0.22	1.61	586.1	40.5	1599.3

*TW = WA+precipitation, CT: Control treatment, DRIP: Dripping system, MIC: Micro-sprinkler system and WA: Water applied by irrigation

Table 2: Comparison of the means of Height (H), diameter at breast height (DBH) and stem volume (V) of the hybrid *Eucalyptus grancam* grown under two in-ground irrigation systems in Aquidauana, State of Mato Grosso do Sul, Brazil

	Treatments				
MAP	MIC	DRIP	CT	DMS	CV (%)
H (m)					
30	14.70^{a}	14.05^{a}	11.68^{b}	1.00	5.8
34	16.22^{a}	16.26^{a}	13.34^{b}	1.35	6.9
37	16.87^{a}	17.10^{a}	14.19^{b}	1.63	8.0
41	17.35^{a}	17.82^{a}	15.74^{b}	1.22	5.7
DBH (cm)					
30	12.53^{a}	11.98^{a}	10.57^{b}	0.89	6.0
34	13.23^{a}	12.80^{a}	11.74^{b}	1.05	6.6
37	13.83^{a}	13.21^{ab}	12.11^{b}	1.59	9.6
41	14.04^{a}	13.70^{ab}	12.86^{b}	1.03	6.0
V (m^{3} ha^{-1})					
30	101.61^{a}	88.24^{a}	57.42^{b}	17.49	16.7
34	124.89^{a}	116.07^{a}	80.38^{b}	20.72	15.2
37	142.28^{a}	130.35^{a}	92.59^{b}	30.40	19.7
41	149.53^{a}	145.98^{a}	114.25^{b}	22.26	12.8

Equal lowercase letters in the treatments do not significantly differ from each other under 95% of significance, MAP: Month after planting, MIC: Micro-sprinkler irrigation system, DRIP: Dripping irrigation system, CT: Control treatment, DMS: Minimum significant difference and CV: Coefficient of variation

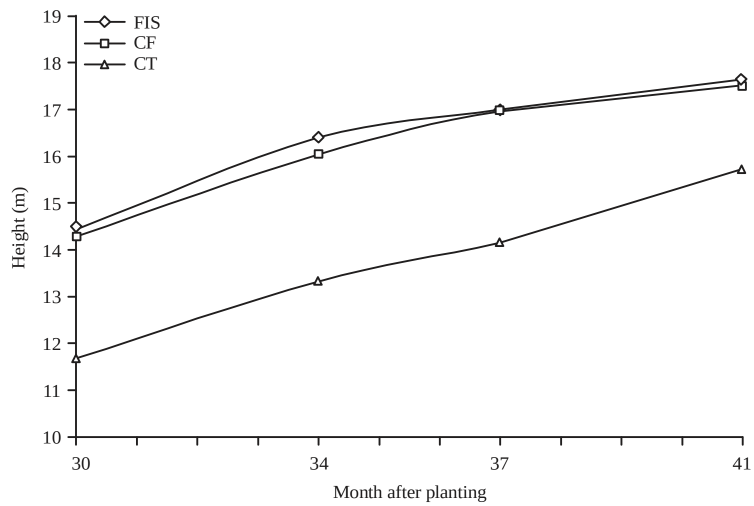

Fig. 2: Height increment of the hybrid *E. grancam* under the treatments of Fertilizing Irrigating System (FIS) and Conventional Fertilization (CF) and Control Treatment (CT)

even under water stress, not significantly reducing growth when irrigation supply is not given (Dos Reis *et al*., 2006).

In relation to diameter increment, trees grown under drip treatment did not differ from trees grown under micro-sprinkler treatment. In contrast, both micro-sprinkler as drip treatments did differ from the control treatment. The drip presented better results in the first two measurements (30th and 34th months after planting), while in the last measurements (37th and 41st) did not significantly differ from the control treatment.

As a result of diameter increment, stem volume was also greater in irrigated treatments, resulting in an increase of 22.6% in volume increment. After the last measurement, trees under micro-sprinkler and drip treatments presented a mean of 149.53 and 145.98 m^3 ha^{-1}, respectively, while the control treatment presented a mean of 114.25 m^3 ha^{-1}.

Dos Reis *et al*. (2006) found similar results on the hybrid *E. grancam* under in-ground irrigation, where at the 38th month after planting, the mean of stem volume was 138.38 m^3 ha^{-1}.

According to Fernandes *et al*. (2015) trees grown under irrigated systems are likely to present better development because of high stomata activity, providing therefore, a high photosynthesis rate, which consequently results in greater biomass increment and higher yield of timber.

De Souza *et al*. (2006) also claimed that yield of timber is straightly influenced by water availability. As water potential (θw) decreases, stomata activity also lowers to not release water vapor to the atmosphere. Thus, CO_2 does not diffuse in from the atmosphere and mineral uptake from the soil also drops, reducing therefore yield of timber.

In relation to fertilization, trees cultured under fertilizing irrigating system and conventional fertilization did not significantly differ in height increment, presenting a mean of 17.66 and 17.52 m, respectively. On the other hand, both treatments did differ from the control treatment which presented a mean of 15.74 m (Fig. 2).

In relation to diameter increment, at the 30th month after planting, fertilizing irrigating system and conventional fertilization resulted in a mean of 14.45 and 14.40 cm, respectively, while the control treatment resulted in a mean of 11.68 cm (Fig. 3).

At the 30th and 34th months after planting, conventional fertilization provided better results when compared to the control treatment, yet they did not differ in the next evaluations (at the 37th and 41st months after planting).

Fertilizing irrigating system and conventional fertilization did not strongly differ in relation to volume increment, yet they considerably differ from the control treatment (Fig. 4). Thus, even though precipitation was quite well distributed along the evaluation period (Fig. 1), irrigation management provided even better culture yield.

Teixeira *et al*. (2011) claimed that, in irrigated sites the supply of nitrogen (N) and potassium (K) applied by fertilizers are more efficient than conventionally done. As much humidity is kept, as much N and K are available into soil solution as well as readily to be uptake by the roots. In addition, K is usually applied as a salt, KCl, therefore requiring favorable soil moisture do not strongly decrease soil osmotic potential.

Likewise, increasing the efficiency on fertilizer apply ends up lowering leaching hazard, avoiding therefore water table pollution (Teixeira *et al*., 2011).

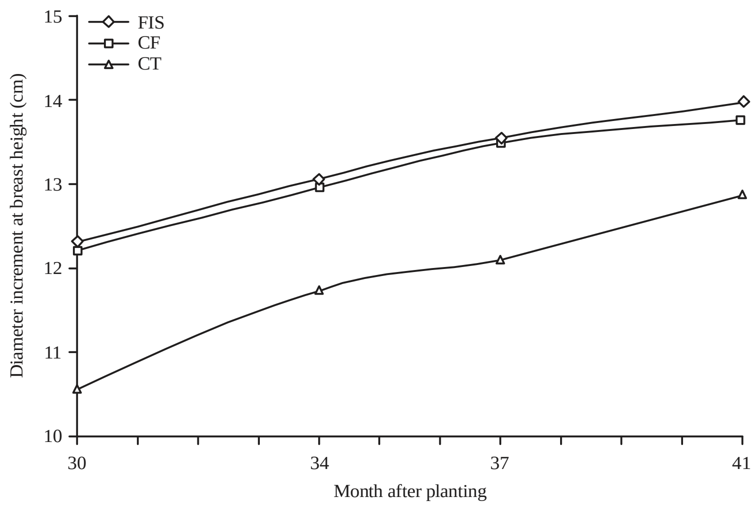

Fig. 3: Diameter increment at breast height of the hybrid *E. grancam* in response to the treatments of Fertilizing Irrigating System (FIS), Conventional Fertilization (CF) and Control Treatment (CT)

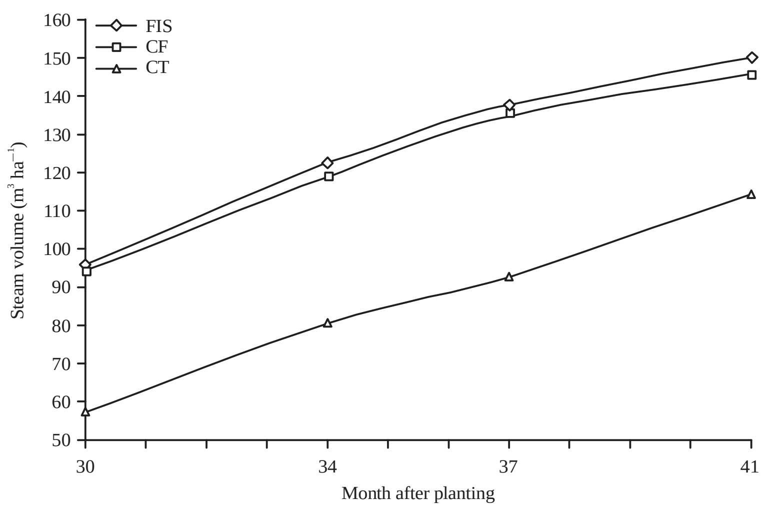

Fig. 4: Stem volume increment of the hybrid *E. grancam* under the treatments of Fertilizing Irrigating System (FIS), Conventional Fertilization (CF) and Control Treatment (CT)

Thus, fertilizing irrigating systems play an important role in the supply of some nutrients, as well as optimizing water use. Also, these systems drop the costs in fertilizing applications as they lower labor and the use of agricultural implements required in conventional fertilization (Boas *et al*., 2006).

In a study done by Teixeira *et al*. (2007) cropping banana under fertilizing irrigating system, was possible to reduce N and K supply without decreasing fruit yield. The same result was found by Pegoraro *et al*. (2013) on *Eucalyptus* sp., where fertilizing irrigating system increased the amount of carbon and nitrogen as well as reduced carbohydrates in the leaf litter compared to *Eucalyptus* sp., grown under conventional fertilization.

CONCLUSION

The micro-sprinkler irrigation system contributes to greater increment in height, diameter at breast height and volume of the hybrid *Eucalyptus grancam*.

The fertilizing irrigating system presents results similar to conventional fertilization. Thus, it can be an alternative when growing *Eucalyptus* spp., under in-ground irrigation systems.

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