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Hydrogel influences in *Eremanthus erythropappus* establishment in different hydric handlings

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ABSTRACT: The efficiency of water use is one of the limiting factors in forest production, since it influences the physiological processes that determine plant growth and development. To store and guarantee the water supply, hydrogels have been used in the production of forest species seedlings. The aim of the present study was to evaluate water management and the use of hydrogels in the initial growth of *Eremanthus erythropappus* (DC.) MacLeish seedlings in pots. The experiment was conducted in a completely randomized design in a 4 × 3 factorial arrangement, being tested the use of hydrogel (no hydrogel (SG) and three types: G1, G2 and G3) and the form of irrigation (no irrigation, pure water irrigation and irrigation with gel solution), in five replications, containing one plant per plot. Evaluations were carried out at 15, 25, 40 and 55 days of the height and diameter of the seedlings, in addition to calculating the daily evapotranspiration and determining, at the end of the experiment, the permanent wilt point (PMP), the dry matter of the aerial part and root. The seedlings under the use of gels G3 and G1 showed higher average height, whereas seedlings irrigated with aqueous solution showed lower results in height and diameter, and its use with planting hydrogel is not recommended. G1 showed satisfactory results, and with G3 they endured a longer period in water deficit stress, reaching the PMP four days after the seedlings with G2 or without the product, and can serve as a differential in the field.

Key words: Candeia; hidroretentor gel; soil conditioners

Hidrogel no estabelecimento de mudas de *Eremanthus erythropappus* sob diferentes manejos hídricos

RESUMO: A eficiência do uso da água é um dos fatores limitantes na produção florestal, uma vez que influencia os processos fisiológicos determinantes ao crescimento e desenvolvimento das plantas. Como forma de promover umidade ao solo, os polímeros hidrorretentores vêm sendo utilizados na produção de mudas de espécies florestais. O objetivo do presente estudo foi avaliar o manejo hídrico e o uso de hidrogéis no crescimento inicial de mudas de *Eremanthus erythropappus* (DC.) MacLeish em vasos. O experimento foi conduzido em delineamento inteiramente casualizado em arranjo fatorial 4 × 3, sendo testados quatro níveis do fator hidrogel (sem hidrogel (SG) e três produtos: G1, G2 e G3) e três níveis do fator irrigação (sem irrigação, irrigação com água pura e irrigação com solução de gel) em cinco repetições, contendo uma planta por parcela. Foram realizadas avaliações aos 15, 25, 40 e 55 dias, da altura e diâmetro das mudas, além de calculada a evapotranspiração diária e a determinação, ao fim do experimento, do ponto de murcha permanente (PMP), da matéria seca da parte aérea e da raiz. As mudas sob utilização dos géis G3 e G1 apresentaram maior média de altura, já as mudas irrigadas com solução aquosa apresentaram resultados inferiores em altura e diâmetro, não sendo recomendado seu uso com hidrogel de plantio. O G1 apresentou resultados satisfatórios, e com o G3 as mudas suportaram um maior período em estresse hídrico, atingindo o PMP quatro dias após as mudas com o G2 ou sem o produto, podendo servir como um diferencial no campo.

Palavras-chave: Candeia; gel hidrorretentor; condicionadores do solo

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Introduction

Eremanthus erythropappus (DC.) MacLeisch, popularly known as candeia, is a native forest species, typically found in shallow and not very fertile soils at altitudes above 900 m, spanning the Midwest and Southeast of Brazil (Scolforo et al., 2012). Its wood is used for making good quality fence posts for its high durability and natural resistance, and it also produces an essential oil, whose active ingredient is alphabisabolol, used in pharmaceutical and cosmetic industries (Kamatou & Viljoen, 2009).

Agricultural and forestry production is dependent on several factors, such as water, nutrients, and light, water being, a limiting factor for the sustainability of the systems (Vicente et al., 2015). Most of the physiological processes that plants perform are directly or indirectly linked to the water resource, since water is the main constituent of plant cells, and can reach 95% of the total weight, participating in the physical, chemical and biological processes essential for their development (Monteiro Neto et al., 2017). In plant development, water plays an important role, in which a small imbalance in its flow, can cause water deficits and malfunction in several cellular processes of plants (Gonçalves et al., 2018).

Water deficit stress can be produced either by the loss of water through transpiration in relation to the absorption by the roots, or by water deficiency in the soil, these processes being influenced by environmental factors and by characteristics of the plant itself. When subjected to water deficit, the plants manifest several morpho-physiological responses, since there is not only one variable that indicates tolerance to drought, and it varies among cultivars, clones, exposure periods, edaphic factors, and others. These plant reactions indirectly result in soil water conservation (Nascimento et al., 2011; Felippe et al., 2020).

Therefore, different parameters have been studied to evaluate the response of plant species to water stress. Among them, morphological variables, such as plant height and diameter, stand out for their ease of measurement and widespread use as important descriptors of native or planted forests around the world. Physiological parameters such as stomatal conductance and transpiration can also be used (Pereira et al., 2010).

In addition to affecting water relations in plants, water deficit is a recurring phenomenon in several and large extensions of cultivated areas of the Brazilian territory, being one of the limiting factors for expansion (Jacinto Junior et al., 2019).

Considering the current global concern with the scarcity of water resources and the high cost of irrigation in certain situations, the search for increased efficiency in water use by crops has been a concern for research, extension and rural producers, since this component occupies a considerable portion of production costs (Ferreira et al., 2012).

In order to reduce costs and increase productivity, there have been several researches aiming at potential gains in the forest production process. In view of this, among the technologies that aim to provide water to crops, the use of soil conditioners, also known as hydrogels, stands out. These are defined as three-dimensional polymeric networks that can retain significant amount of water into its structure and subsequent release, which, has been widely used in agriculture (Ferreira et al., 2014; Vicente et al., 2015).

Hydrogel is a promising product, say Scolforo et al. (2012), but further research is needed regarding its use in seedlings of the species *E. erythropappus*. Thus, the objective was to evaluate the water management and the use of different types of hydrogel, under potting conditions, on the initial growth of *E. erythropappus* (candeia) seedlings.

Materials and Methods

The study was conducted in the greenhouse of the Forest Nursery of the Universidade Federal de Lavras (UFLA), with candeia seedlings planted in pots, under monitored microclimate conditions, and the data stored during the experimental period, by means of a Thermohygrometer datalogger that has a combined sensor for temperature (°C) and relative air humidity (RH).

The soil used had the following chemical and physical characteristics: sand contente = 210 g kg^{-1}; silt = 120 g kg^{-1}; clay = 670 g kg^{-1}; pH in water = 5.4; organic matter = 13.5 g kg^{-1}; P (Mehlich-1) = 1.2 mg dm^{-3}; K = 37 mg dm^{-3}; Ca = 1.3 $cmol_c$ dm^{-3}; Mg = 0.3 $cmol_c$ dm^{-3}; Al = 0.1 $cmol_c$ dm^{-3}; H + Al = 2.2 $cmol_c$ dm^{-3}; base sum = 1.7 $cmol_c$ dm^{-3}; effective CTC = 1.8 $cmol_c$ dm^{-3}; CTC pH 7 = 4.0 $cmol_c$ dm^{-3}; base saturation = 44%; Al saturation = 5%; Zn = 1.2 mg dm^{-3}; Fe = 32.5 mg dm^{-3}; Mn = 5.6 mg dm^{-3}; Cu = 2.1 mg dm^{-3}; B = 0.05 mg dm^{-3}; S = 62.7 mg dm^{-3}; and, P-rem = 5.1 mg L^{-1}. These analyses were performed in the Soil Fertility Laboratory of the Soil Science Department at UFLA.

The candeia seedlings were produced in 110 cm^3 tubes and, at five months of age, were planted in polyethylene pots with 5 dm^3 capacity, when they had, on average, 30 cm height and 4 mm diameter of the collar. The polyethylene vase held 4 kg of dry soil, previously sieved with a 4 mm mesh.

The hydrogels used are potassium-based, and considered superabsorbent polyacrylate copolymers, this information being provided by the manufacturers of the products used in this experiment. As a way to better characterize the three hydrogels, the swelling test was performed, which consists in obtaining the absorption equilibrium (AE) of the hydrogels. In addition, the electrical conductivity (EC) and the pH of the products were measured, and a water retention test was performed (Table 1).

Table 1. Equilibrium absorption (EA), percent water holding capacity (WHC), electrical conductivity (EC) and hydrogen potential (pH) of the different types of hydrogels used.

Hydrogel	EA	WHC (%)	EC (µS cm^{-1})	pH
G1	150 . P	75.5	1040	7.37
G2	350 . P	78.9	641	3.37
G3	175 . P	64.0	1020	7.50

For the water retention test, 1 g of hydrogel was dissolved in 400 mL of water, which was homogenized and hydrated for 30 min to reach its maximum water absorption capacity. Subsequently, the hydrogels were filtered with a filter capable of retaining particles larger than 10 microns. The water holding capacity (WHC) was determined by Equation 1.

$$\mathrm{WHC}(\%) = \left(\frac{m_1}{m_1 + m_2}\right) \cdot 100 \tag{1}$$

where:

m_1 - weight of hydrogel retained on the filter used to separate the compound; and,

m_2 - weight of the liquid part that passed through the filter.

In order to evaluate the responses to water management and the use of hydrogels, the experiment was conducted in an entirely randomized design with a 4 × 3 factorial arrangement, with four hydrogel factor levels (no gel and three products: G1, G2 and G3) and three irrigation factor levels (no irrigation, irrigation with pure water and irrigation with gel solution), in five repetitions, with one plant per plot (Table 2).

The pots were filled with hydrogel and soil evenly, and 1 g of dry hydrogel was provided per 4 kg of dry soil, according to the treatments used (Table 2). The soil was moistened with 700 mL of water, a value referring to the half of water needed to reach 60% of field capacity, which was calculated based on the moisture retention curve of the soil used, characterized by Baldo et al. (2009). After planting the candeia seedlings, the pots of all treatments were hydrated with the remaining water needed to reach 60% of field capacity (700 mL), in order to promote an increase in the contact area of the root system with the soil.

The seedlings kept at 60% of field capacity were irrigated every three days and the quantification of the water to be applied was done by weighing the pots, being placed at their initial weight (4 kg of soil + water to saturate the soil at 60% of field capacity). Its application was done using a graduated cylinder, and was maintained until the 50 day of the experiment in the treatments with irrigation, at which time irrigation was interrupted and the permanent wilting point of the seedlings in the treatments with some type of irrigation was observed.

Table 2. Definition of the twelve treatments combining the application of the four levels of the hydrogel factor at planting (Factor A) and the three levels of the post-planting seedling irrigation factor (Factor B), in pots with 4 kg of dry soil for the planting of *Eremanthus erythropappus* seedlings.

Factor A	Factor B
Without hydrogel (SG)	Without irrigation (SI)
Without hydrogel (SG)	Irrigation with pure water (H_2O)
Without hydrogel (SG)	Irrigation with gel solution (GEL IR)
Hydrogel 1 (G1)	Without irrigation (SI)
Hydrogel 1 (G1)	Irrigation with pure water (H_2O)
Hydrogel 1 (G1)	Irrigation with gel solution (GEL IR)
Hydrogel 2 (G2)	Without irrigation (SI)
Hydrogel 2 (G2)	Irrigation with pure water (H_2O)
Hydrogel 2 (G2)	Irrigation with gel solution (GEL IR)
Hydrogel 3 (G3)	Without irrigation (SI)
Hydrogel 3 (G3)	Irrigation with pure water (H_2O)
Hydrogel 3 (G3)	Irrigation with gel solution (GEL IR)

In addition to the different types of planting hydrogels, the concomitant use of irrigation with pure water or with aqueous solution with a gel suitable for irrigation was tested until day 50 after the installation of the experiment. According to the manufacturer's directions, 1 g of the gel itself was placed for every 20 L of water, and kept for 30 minutes to be completely dissolved and mixed before use, in order to avoid its deposition at the bottom of the container.

The treatments received that received only irrigation The initial pots until they reached 60% of field capacity, were until the 30th day of permanent experiment, due to the verification of the visual state of wilting, remaining in the pots until the evaluation of the dry matter of the part aerial (DMPA) and root dry matter (RDM) at the end of the experimental period.

Every three days irrigation was performed. However, the quantification of daily evapotranspiration (ET) was obtained only at 15, 25, 40 and 55 days. In the treatments without irrigation that were evaluated until the 30th day of the experiment, ET was quantified at days 15 and 25.

To determine ET at 15, 25, 40 and 55 days, the methodology used by Kobayashi (1996) was used as a reference. It is calculated using the difference between the weight of the previous evaluation, dividing the accumulated weight loss of the last measurement by three, and the current weight of the pot, in relation to the area of the upper section of the pot, in square meters, according to Equation 2.

$$\mathrm{ET_i} = \frac{P_{i-1} - P_i}{A \cdot 1{,}000} \tag{2}$$

where:

ET_i - daily evapotranspiration (mm);

P_{i-1} - weight of the vessel the day before (g);

P_i - weight of the vessel on the day (g);

A - area of the vessel upper section (m²).

The morphological parameters measured were: the height of the aerial part (H), measured from ground level to the insertion of the last leaf with the help of a ruler graduated in centimeters; the diameter of the collar (CD) of the seedlings, measured at ground level with the aid of a digital pachymeter, accurate to 0.02 mm. As with evapotranspiration, plants were evaluated for the no irrigation treatments at 15 and 25 days, and for the others at 15, 25, 40, and 55 days after planting.

In addition, at the end of the experimental period, the aerial part of the seedlings was collected by sectioning it from the root ball using scissors, and the root system was collected with the help of sieves with 3 to 7 mm mesh, under running water, to avoid root disruption and loss. All the material was placed in identified paper bags and dried in a forced air circulation oven (65°C for 72 hours) and then weighed to determine the dry matter of the part aerial (DMPA) and root dry matter (RDM), respectively.

After planting and submission to the treatments, until day 64, evaluations of the symptoms of water stress in the plants were carried out, visually following the evolution of the treatments as to the permanent wilting point, by means of photographic records. The permanent wilting point was evaluated at two different moments, the first for the treatments without irrigation, until day 30, while for the treatments in which irrigation was interrupted on day 50, the evaluation occurred from this moment on, until the seedlings died on day 64. The data of the morphological parameters measured in each evaluation were submitted to variance analysis (ANOVA), and the means were compared, when necessary, by Tukey test, at 5% error probability.

Results and Discussion

Daily evapotranspiration (ET)

Figure 1 shows the average daily values of temperature and relative humidity inside the greenhouse during the experimental period. It is possible to observe that the average temperature varied around 19.8 °C, with a maximum of 22.8 °C and a minimum of 16.0 °C (Figure 1A). The average value of relative humidity found was 76.0% with extreme values, maximum of 88.7% and minimum of 63.2% (Figure 1B).

When performing the analysis of variance, significant differences were verified for evapotranspiration at 15 and 25 days after planting, and it was possible to notice that the evaluation made 15 days after planting obtained an overall average of daily evapotranspiration higher than the one found in the evaluation made 25 days after planting (Figure 2). This condition can be justified by the observation of a decrease in the average temperature of 0.71 °C in the evaluation performed at 25 days when compared to the average temperature in the evaluation period made 15 days after planting.

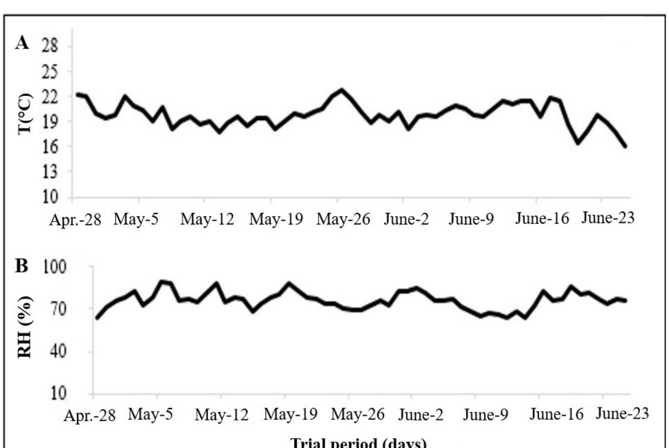
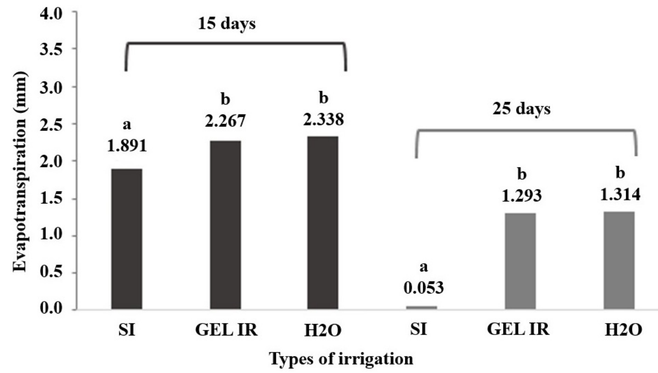


Figure 1. Average values of temperature - T (A), and relative air humidity - RH (B) inside the greenhouse during the experimental period.



Averages followed by the same letter, on the same date, do not differ, by Tukey test at 5% probability.

Figure 2. Daily evapotranspiration at 15 and 25 days in *Eremanthus erythropappus* seedlings, as a function of the type of irrigation adopted (SI - Without irrigation; GEL IR - Irrigation with gel solution; H_2O - Irrigation with pure water).

Another factor that contributed to this difference in daily evapotranspiration, possibly, was the variation in relative humidity, presenting, including, in the evaluation made at 15 days after planting, the lowest daily average during the entire experimental period, with 63.2%.

When verifying the values obtained for the daily evapotranspiration variable, it can be seen that there was no significant interaction between the types of irrigation used in the experiment and the different hydrogels, within the analyzed conditions, at 15 and 25 days. However, there was a significant effect on how the irrigation was performed.

The lack of significant results in the interaction may have occurred due to the higher frequency of irrigation, which did not allow the maximum potential of the hydrogel to be reached on par with those treatments without it. This condition was confirmed by Navroski et al. (2014), in which more frequent irrigation, in this case every three days, did not show potential gains in the treatments using the polymer.

At 15 and 25 days, there was a distinct trend for the types of irrigation used, in which the treatments without irrigation showed a lower average evapotranspiration rate, which is justified by the low availability of water throughout the experimental period for these treatments (Figure 2).

Similar results were found by Felippe et al. (2020), stating that the lower water loss by the plants, in the presence of water deficit, is a form of defense of the plants against dehydration, by closing the stomata. Jacinto Junior et al. (2019) observed, as in the present study, that the lower evapotranspiration is possibly linked to the closure of stomata and the reduction of transpiration as a conditioning factor for the risk of dehydration. These factors are evidenced as the availability of water in the soil is reduced, thus causing a reduction in the photosynthetic rate.

When checking the response of the gel suitable for irrigation, it was observed that the results were no better than those obtained by using only water for irrigation. Considering only the treatments that were irrigated, either by pure water or by irrigation gel, there was no significant difference between the treatments evaluated at 40 and 55 days after planting.

These results resemble the study conducted by Marques et al. (2013) with different doses of hydrogel in coffee culture, supporting the point that soil moisture always remained close to 60% of field capacity.

In work with *Corymbia citriodora* and different doses of hydrogel, Bernardi et al. (2012) observed that the higher the concentration of polymer used, the greater was the water retention, this water being less available to the atmosphere, which reduces evapotranspiration. Given this, it is necessary to conduct further experiments using different doses of the hydrogels under conditions similar to this work in order to verify water retention at different concentrations.

Morphological parameters of seedling growth

With the values obtained from the measurement of the height of the candeia seedlings, it was found that there was no significant interaction between the types of irrigation and the hydrogels evaluated. However, there was a significant effect of the way irrigation was performed, at 15 and 25 days after planting, only for height, and interaction between the factors for collar diameter at 25 days.

When analyzing the main effect of irrigation on seedlings, it can be seen that water restriction significantly affected plant growth at 15 and 25 days (Table 3). The seedlings in the treatments without irrigation presented the lowest average growth in height, since, according to Taiz & Zeiger (2004), the lower the availability of water, the greater the negative effect on the cell division coefficient and cell expansion, preventing vegetative growth of the plants.

The treatments that were not irrigated showed lower average height growth in the seedlings, as found by Butrinowski et al. (2013) with *Eucalyptus grandis*, in which they found that water deficiency directly affected the growth in height and diameter, reducing cell expansion and cell wall formation, and indirectly influenced the reduction in the production of growth regulators.

Regarding the significant interaction for collar diameter at 25 days after planting, it can be noted that seedlings with gel solution suitable for irrigation and without the addition of planting hydrogel showed a gain in diameter when compared to seedlings irrigated with pure water in the same condition (Table 4). Considering only hydrogel 3, the absence of irrigation and irrigation with pure water resulted in higher mean values for collar diameter at 25 days, not statistically different.

Table 3. Average values (cm) obtained for the variable height (H) of Eremanthus erythropappus seedlings, at 15 and 25 days after planting, under different types of irrigation.

Irrigation	15 days	25 days
	Averages	
SI	30.44 ^{b}	31.11 ^{b}
GEL IR	31.62 ^{ab}	33.12 ^{a}
H_2O	33.41 ^{a}	34.79 ^{a}

Averages followed by at least one letter in the column do not differ by the Tukey test at 5% probability of error. SI - Without irrigation; GEL IR - Irrigation with gel solution; H_2O - Irrigation with pure water.

Table 4. Average values (mm) for the collar diameter (CD) of *Eremanthus erythropappus* seedlings, at 25 days after planting, as a function of the use of different types of irrigation and hydrogels.

Irrigation	Hydrogel			
	G1	G2	G3	SG
GEL IR	6.11 ^{Bab}	5.54 ^{Bab}	4.78 ^{Bb}	6.30 ^{Aa}
H_2O	5.89 ^{Ab}	5.67 ^{Aa}	6.10 ^{Aa}	5.01 ^{Ab}
SI	5.38 ^{Ab}	4.69 ^{Aa}	5.83 ^{Aab}	5.42 ^{Aab}

Averages followed by at least one same lower case letter in the column and upper case in the row do not differ by the Tukey test ($p < 0.05$). SI - Without irrigation; GEL IR - Irrigation with gel solution; H_2O - Irrigation with pure water; SG - Without hydrogel; G1- Hydrogel 1; G2 - Hydrogel 2; G3 - Hydrogel 3.

When looking at planting hydrogel 3, it can be seen that the seedlings irrigated with pure water showed larger diameter averages when compared to the seedlings from the other types of irrigation. As in the work performed by Bernardi et al. (2012) in the growth of *Corymbia citriodora* seedlings, via micro sprinkler, there was a positive effect for height of the aerial part and collar diameter with the use of hydrogel. For the other treatments, seedlings with different brands of hydrogels were not influenced by irrigation using pure water or in those in water deficit.

The use of hydrogel, in the growth analysis of young plants of *Enterolobium contortisiliquum*, a tree species native to Brazil, also provided higher gains in height compared to treatments in the absence of the polymer, as reported by Silva et al. (2019).

In the other evaluations carried out at 40 and 55 days after the implementation of the experiment it was possible to note, considering only the irrigated treatments, that there was a significant effect, both for the type of hydrogel and for the irrigation used in the height development of the seedlings. However, for the CD there was a significant effect of the interaction between the factors evaluated, at 40 and 55 days after planting.

When observing the different hydrogels, it was found that hydrogel 3 provided the greatest gain in seedling height, in both evaluations, especially when compared to hydrogel 2 (Table 5).

No influence of the water retention capacity of the hydrogels on the height gain of the seedlings was observed in this experiment, since hydrogel 3, with the lowest retention capacity, showed the highest values for the variable. Hydrogel 2 showed the highest water retention capacity, and this

Table 5. Average values (cm) for height (H) of *Eremanthus erythropappus* seedlings, at 40 and 55 days after planting, under the influence of different hydrogels.

Hydrogel	40 days	55 days
G2	34.26 ^{b}	37.17 ^{b}
SG	35.61 ^{ab}	37.82 ^{ab}
G1	36.89 ^{a}	39.78 ^{ab}
G3	38.70 ^{a}	41.61 ^{a}

Averages followed by at least one letter in the column do not differ by Tukey test at 5% probability of error. SG - Without hydrogel; G1- Hydrogel 1; G2 - Hydrogel 2; G3 - Hydrogel 3.

characteristic may have negatively influenced and contributed to the results presented, since in this experiment, the field capacity was maintained near 60% during the entire evaluation period, which may have caused a water excess, leading to a hypoxic condition.

Analogously, Navroski et al. (2014), testing the influence of hydrogel and different irrigation frequencies, found that the presence of the hydroretainer polymer was positive in height when evaluated at a longer interval between irrigations.

Regarding the evaluations performed at 40 and 55 days, a significant difference was also observed for the type of irrigation used, in which possibly, the values for seedlings irrigated with the aqueous solution of gel suitable for irrigation were significantly lower, compared to seedlings from treatments using only water (Table 6).

When performing the interaction between hydrogels and irrigation types for the diameter of the collar of *Eremanthus erythropappus* seedlings at 40 and 55 days of installation, the differences between the means of the treatments were evident (Table 7).

The use of the aqueous solution of gel suitable for irrigation associated with hydrogel for planting 3 caused the seedlings to present the lowest average for the colt diameter variable in comparison with the seedlings of the treatments without the use of hydrogel. As in the previous evaluation, a negative relationship is observed in the use of the aqueous solution containing gel for irrigation and the use of the hydrogel for planting, especially for hydrogel 3. This may indicate a restriction in the use of the aqueous gel solution for irrigation when using hydrogels suitable for planting.

Table 6. Average values (cm) for height (H) of *Eremanthus erythropappus* seedlings, at 40 and 55 days after planting, under different types of irrigation.

Irrigation	40 days	55 days
GEL IR	35.02 b	37.80 b
H_2O	37.71 a	40.39 a

Averages followed by at least one letter in the column do not differ by the F test at 5% probability of error. GEL IR - Irrigation with gel solution; H_2O - Irrigation with pure water.

The use of aqueous solution with planting hydrogel affected seedling height at 40 and 55 days after planting. This effect can be explained by the aqueous solution of the irrigation gel presenting a higher viscosity when compared to pure water, which viscosity possibly favored water retention by the hydrogel, promoting hypoxia and impairing its effect on the plants.

After almost two months of planting, in the evaluation performed at 55 days of installation, it was possible to identify, the average positive effect of using the aqueous solution containing gel suitable for irrigation in the absence of planting hydrogel. Then, at the end of the experimental period, the dry matter of the part aerial (DMPA) and the root dry matter (RDM) were measured. In both variables a significant interaction was observed between the different hydrogels and types of irrigations used.

Table 8 confirms what was expected in relation to the treatments without irrigation for the variable DMPA, in which lower values are observed when compared to the other irrigated treatments. However, analyzing the hydrogels used, the highest value was obtained for those treatments using hydrogels 1 and 3.

It can also be seen that the water retention capacity of the hydrogels had little relation with the increase of the seedlings aboveground dry matter, since the seedlings with the hydrogel with the highest water retention capacity obtained the lowest mean DMPA, along with the treatments without the use of hydrogel. Similar results were found by Marques et al. (2013), in which coffee seedlings in the treatment without hydrogel and without irrigation showed the lowest aerial part values, compared to seedlings in the other treatments using the product.

Note that the seedlings in the treatments without irrigation and those irrigated with pure water, in the presence of hydrogel 2 and without the use of hydrogel reached the lowest average values in this variable, when compared with seedlings using hydrogels 1 and 3. However, seedlings from treatments irrigated with the aqueous solution of gel suitable

Table 7. Average values (mm) for the collar diameter of *Eremanthus erythropappus* seedlings, at 40 and 55 days after planting, considering only the irrigated and hydrogel treatments.

Irrigation	40 days				55 days			
	G1	G2	G3	SG	G1	G2	G3	SG
GEL IR	6.46 ABa	5.85 Bab	5.15 Bb	6.60 Aa	6.95 Aa	6.23 Aa	6.06 Aa	6.98 Aa
H_2O	6.40 Aa	6.14 Aa	6.42 Aa	5.17 Ab	6.70 Aa	6.45 Aa	6.67 Aa	5.65 Ab

Averages followed by at least one same lower case letter in the column and upper case in the row do not differ, respectively, by the F test and Tukey at 5% error probability. GEL IR - Irrigation with gel solution; H_2O - Irrigation with pure water; SG - Without hydrogel; G1- Hydrogel 1; G2 - Hydrogel 2; G3 - Hydrogel 3.

Table 8. Average values (g) obtained for dry matter of the part aerial (DMPA) and root dry matter (RDM) of *Eremanthus erythropappus* seedlings, after 65 days of planting, as a function of different types of irrigation and hydrogels.

Irrigation	DMPA				RDM			
	G1	G2	G3	SG	G1	G2	G3	SG
GEL IR	7.77 Aa	4.78 Ba	5.17 Bb	4.67 Bb	6.15 Ab	5.27 Bb	5.52 Ba	4.77 Ca
H_2O	6.62 Bb	4.92 Da	7.48 Aa	5.54 Ca	7.46 Aa	7.13 Aa	5.39 Ba	4.78 Ca
SI	4.79 Ac	3.31 Bb	4.44 Ac	3.49 Bc	2.05 Ac	1.33 Bc	1.50 Bb	1.43 Bb

Averages followed by at least one same lower case letter in the column and upper case in the row do not differ by the Tukey test at 5% error probability. SI - Without irrigation; GEL IR - Irrigation with gel solution; H_2O - Irrigation with pure water; SG - Without hydrogel; G1- Hydrogel 1; G2 - Hydrogel 2; G3 - Hydrogel 3.

for irrigation presented the highest averages using hydrogel 1, which contradicts the results found in the CD variable, in which the concomitant use of planting hydrogel with the aqueous solution of gel for irrigation at 25 and 40 days of evaluation, was harmful.

The use of hydrogel 1 proved to be satisfactory for both the DMPA and the RDM variables, with, in the latter case, the highest average biomass values for seedlings from treatments irrigated with pure water. The treatments irrigated with the aqueous solution of gel suitable for irrigation showed, as in the DMPA variable, higher average biomass in the seedlings with hydrogel 1.

For the treatments without irrigation, it is observed that hydrogel 1 guaranteed a greater amount of root dry matter in *Eremanthus erythropappus* seedlings compared to the other treatments, which shows once again its potential for use.

This good adaptation of the RDM variable using hydrogel is also seen in work done by Navroski et al. (2014) with eucalyptus, in which the authors report a biomass gain and a higher presence of roots in the hydrogel treatments. In contrast, Souza et al. (2016), regarding root dry matter, observed no significant differences in biomass gain using hydrogel.

It should be noted that the experiment was conducted in pots under controlled conditions, in which the treatments with irrigation were kept moist, serving only as an indicator of the actual behavior of the use of hydrogel and different irrigation managements under field conditions.

Permanent wilting point (PWP)

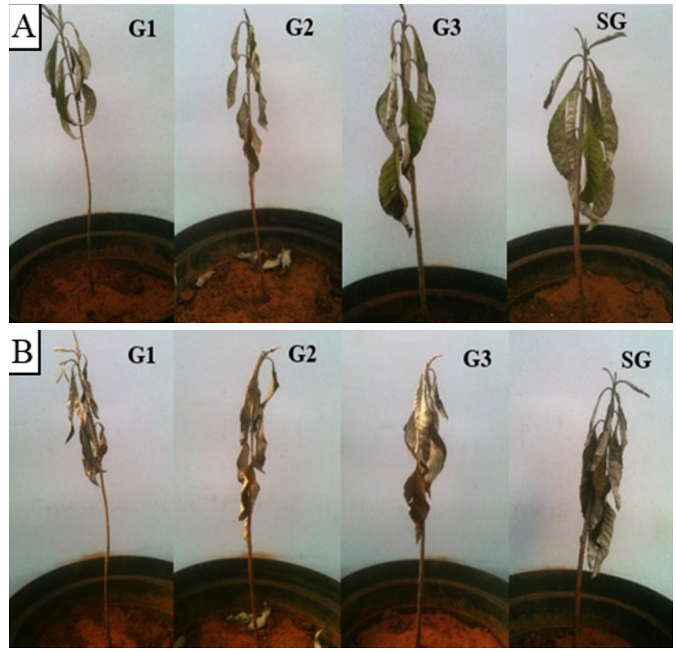
From the visual analyses carried out during the experiment, illustrated by means of photographic records, it was observed that the plants in the treatments without irrigation were under considerable water stress at the end of the 25 days of planting (Figure 3A). At 29 days after experiment installation, with fully dried leaves, all treatments reached the permanent wilting point (Figure 3B).

Backing up the results found, Navroski et al. (2014) state that irrigation, when performed only at planting time, causes early seedling mortality, since seedlings need water in a satisfactory quantity for their development, guaranteed with irrigations after planting.

Despite showing significantly higher mean values of DMPA and RDM, seedlings with hydrogels 1 and 3 did not show visual differences in PWP, compared to the other treatments, in the evaluations without irrigation.

For the treatments that received some type of irrigation, PWP analysis was only possible after irrigation was stopped, at 50 days after planting. The first wilting symptoms appeared seven days after irrigation was stopped for seedlings in the treatments without the use of hydrogel and for hydrogel 2, regardless of the type of irrigation used, entering permanent wilting point at ten days after irrigation was stopped (Figure 4A).

The seedlings in the treatments that received hydrogel 1 and hydrogel 3 showed the first wilting symptoms on the tenth day after the interruption of irrigation, reaching their respective permanent wilting points on the fourteenth day without irrigation (Figure 4B), with no difference between the types of irrigation used previously.



SG - Without hydrogel; G1- Hydrogel 1; G2 - Hydrogel 2; G3 - Hydrogel 3.

Figure 3. Evaluation of water stress symptoms in *Eremanthus erythropappus* plants in the absence and presence of different hydrogels after 25 days of planting without irrigation (A) and after 29 days of planting without irrigation (B).

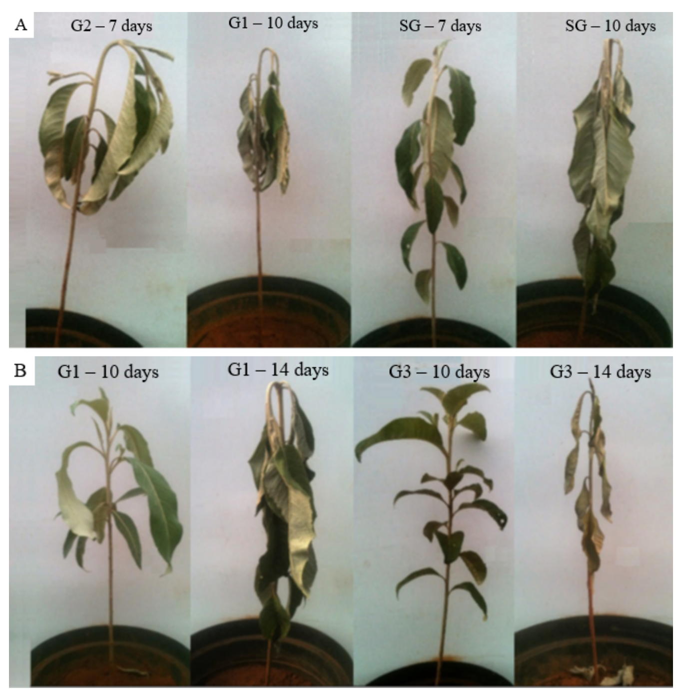


Figure 4. Evaluation of water stress symptoms in *Eremanthus erythropappus* seedlings using (A) hydrogel 2 (G2) and in seedlings without the use of hydrogel (SG), at seven and 10 days after the interruption of irrigation and (B) hydrogel 1 (G1) and hydrogel 3 (G3), at 10 and 14 days after the interruption of irrigation.

These results are important from a practical and economic point of view, since the use of hydrogels 1 and 3 provided a 28.6% gain in extra days without irrigation when compared to the treatments without gel or with hydrogel 2. As pointed out by Saad et al. (2009), these products enable the delay of a new irrigation, and consequently, economic gains, in the possibility of waiting for rains in this period.

Conclusions

The seedlings showed different responses to the types of hydrogel used, and hydrogel 1 promoted the greatest accumulation of root dry matter, which may contribute to the establishment of seedlings in the field, since it is an important variable in the complex system soil, water, and plant.

The seedlings irrigated with the aqueous solution containing the proper gel for irrigation showed a negative response to the height and diameter of the collar in the presence of the hydrogel, and its use concomitantly with the hydrogel for planting is not recommended.

The seedlings with hydrogels 1 and 3 were able to withstand the water deficit for a longer period of days until reaching the permanent wilting point, and their use may be a differential in field conditions.

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Compliance with Ethical Standards

Author contributions: Conceptualization: JAPJ, EMN, LAM; Data curation: JAPJ, EMN, LAM, LVS; Formal analysis: JAPJ, EMN, LAM, LVS; Methodology: JAPJ, EMN, LAM; Project administration: LAM; Resources: LAM; Supervision: LAM, SAB; Validation: LAM, SAB; Writing – original draft: JAPJ, EMN, LAM, MLMA, SAB; Writing – review & editing: JAPJ, EMN, LAM, MLMA, SAB.

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