EFFECT OF HYDROGEL APPLICATION AND IRRIGATION FREQUENCY ON THE GROWTH OF PIONEER AND CLIMAX PLANTS FOR THE RECOVERY OF SEMIARID AREAS

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ABSTRACT: The availability of resources such as nutrients and water plays an important role in the development and survival of young plants, mainly those used in the recovery of degraded areas. The soil characteristics and the climatic conditions of the Brazilian semiarid show the need for constant irrigation to mitigate the difficulty of storing water. In this sense, hydrogel is able to store water and release it little by little, which can facilitate the recovery of areas undergoing a degradation process. Therefore, the aim of this work was to evaluate the irrigation frequency and the effect of hydrogel on the growth of young plants in the recovery of a degraded area in the semiarid region of Ceará. For this, 180 seedlings of 8 species native to the Caatinga were distributed into nine plots and submitted to hydrogel application with daily irrigation (T1), hydrogel application with irrigation 3 times a week (T2) and no hydrogel application with daily irrigation (T3), during six months, with continuous monitoring for vertical and horizontal growth and survival. Hydrogel application increased the growth in height and diameter, as well as the basal area. In addition, the survival rate of T1 and T2 was higher, with pioneer species being the most benefited. Thus, hydrogel application can be considered an efficient strategy aimed at the development of species in areas with water limitations such as the semiarid region of Brazil; mainly in the recovery of areas, by providing growth and survival of pioneer and native species, which will protect the soil from erosion and will support the development of other slow growing species.

KEYWORDS: Caatinga; Horizontal structure; Vertical structure; Polymers; Water retention.

INFLUÊNCIA DO HIDROGEL E FREQUÊNCIA DE IRRIGAÇÃO NO CRESCIMENTO DE PLANTAS PIONEIRAS E CLÍMAX PARA A RECUPERAÇÃO DE ÁREAS DO SEMIÁRIDO

RESUMO: A disponibilidade de recursos como nutrientes e água desempenha um papel importante no desenvolvimento e sobrevivência de plantas jovens, principalmente na recuperação de áreas degradadas. As características do solo e as condições climáticas do semiárido brasileiro evidenciam a necessidade de irrigação constante para contrapor a dificuldade de armazenamento de água. Nesse sentido, o hidrogel é capaz de armazenar água e liberá-la aos poucos, podendo facilitar a recuperação de uma área sob processo de degradação. Diante disso, o objetivo deste trabalho foi avaliar a frequência de irrigação e o efeito do hidrogel no crescimento de plantas jovens na recuperação de área degradada no semiárido cearense. Para isso, 180 mudas de 8 espécies nativas da Caatinga foram distribuídas em nove parcelas e submetidas a aplicação de hidrogel com irrigação diária (T1), hidrogel com irrigação 3 vezes por semana (T2) e sem hidrogel com irrigação diária (T3), durante seis meses, com monitoramento contínuo quanto ao crescimento vertical, horizontal e à sobrevivência. A aplicação de hidrogel beneficiou o crescimento em altura e diâmetro, assim como área basal. Além disso, a taxa de sobrevivência de T1 e T2 foi maior, sendo as espécies pioneiras as mais beneficiadas. Dessa forma, a aplicação do hidrogel pode ser considerada uma estratégia eficiente quando se busca o desenvolvimento de espécies em áreas com limitações hídricas como a região semiárida; principalmente na recuperação de áreas, por proporcionar o crescimento e sobrevivência de espécies pioneiras e nativas, que irão proteger o solo de erosões e darão suporte para o desenvolvimento de outras de crescimento lento.

PALAVRAS CHAVE: Caatinga; Estrutura horizontal; Estrutura vertical; Polímeros; Retenção de água.

INTRODUCTION

Water is an essential strategic resource in the development of all sectors of the economy (Folhes et al. 2009). The predominant vegetation in the northeastern region of Brazil is the Caatinga, which covers an area of 912,529 km², with the semiarid climate as its main climate, which records average temperatures from 25° to 30°C and irregular precipitation, with annual averages between 400 and 1200 mm (Tabarelli et al., 2018). Given the low water availability, added to its inadequate use and without proper management of water resources, phenomena such as difficulty in storing water and consequent soil desertification in the semiarid region become evident.

Irrigation, a human activity that most demands water resources, is responsible for more than 70% of water demand in all continents (Xu et al., 2019). However, in semiarid regions such as northeastern Brazil, where precipitation is concentrated in only four months of the year, water availability limits agricultural productivity, intensified by to the low use of modern production inputs and the low agricultural suitability of regional soils to retain water even with constant irrigation (Ferrari et al., 2015).

Inadequate soil use and management and the replacement of native vegetation cover by cultivated areas favor soil degradation (Flach et al., 2020), influencing sustainable development. As a strategy to reduce the growing environmental degradation, forest recovery is promoted through the improvement of the quality and quantity of ecosystem services, such as reduction of soil erosion and maintenance of biodiversity (Bessa et al., 2019). However, recovery in semiarid environments is hampered by environmental weaknesses, whether climatic or edaphic inherent in these regions, which have scarcity and irregularity in the rainfall regime, with periods of intense drought, high evapotranspiration rates, predominance of shallow soils prone to salinity and poor water retention capacity (Gonçalves et al., 2019).

The water problem found in this region justifies the study, emergence and improvement of new techniques seeking to minimize the effects of water stress on plant species, reducing crop losses, adjusting the scarcity of water resources and promoting the development of seedlings in plantations aimed at the recovery of degraded areas (Fidelis et al., 2018).

In this context, hydrogel appears as a solution to increase the soil water storage capacity (Mendonça, 2013). The use of hydrogel in soil has been effective, as plant roots develop and grow inside hydrogel granules, increasing contact between roots, water and nutrients (Monteiro et al., 2016). Hydrogel is used as soil improver aiming at increasing the soil water or nutrient retention capacity, enabling the reduction of irrigation frequency and costs, reducing the tendency of compaction and surface water runoff, reducing seedling mortality and consequently the use of replanting labor (Montesano et al., 2015).

These properties associated with hydrogel are quite relevant when it comes to environments with high water scarcity levels, such as the Brazilian semiarid region. Despite having been extensively studied, there are few studies that have evaluated hydrogel application in degraded areas, especially in the Brazilian semiarid region and using species native to the Caatinga. Therefore, the aim of this work was to evaluate the irrigation frequency and the effect of hydrogel on the development of seedlings used in the recovery of a degraded area in the semiarid region of Ceará.

MATERIAL AND METHODS

Description and preparation of the study area

The study was carried out in an area of 393 m² (4°58'38.50" N and 39°3'30.69" S) located at the

Federal Institute of Education, Science and Technology of Ceará (IFCE) – campus of Quixadá. The campus is located in the "Sertão Central" region of Ceará, with predominance of the Tropical Warm Semiarid climate, with average temperature from 26º to 28ºC, relative humidity around 65%, and annual rainfall of 838.1 mm, with rainfall in periods from February to April (IPECE, 2017). Dystrophic red-yellow podzolic soil (reference) was identified in the study area and degradation was also identified due to the grounding that occurred during the construction and paving of the campus roads.

The territory of the municipality of Quixadá is inserted in the central region of dissected areas belonging to the 'Sertaneja' Depression geomorphological unit of Ab'Saber (1969), with altimetry from 80 to 400 meters within crystalline residual massifs (Bezerra, 2009). The region is composed of Non-calcic brown, Solodic Planosol, Red-yellow Podzolic, Litholic, Rhegosol and Solodized Solonetz soils (IPECE, 2017). Specifically, in the study area, dystrophic red-yellow podzolic soil was identified, which has as its main characteristic the abundance of minerals, originating from the direct rock breakdown without transport involvement for its accumulation (Bezerra, 2009). It should be highlighted that in the study area, degradation was also identified due to the grounding that occurred during the construction and paving of the campus roads.

Before starting the experiment, the area was cleared in order to eliminate individuals of other species, such as grasses, which could compete for resources. Throughout the experiment, the emergence of invasive or opportunistic species was monitored and eliminated. After cleaning, pits of 20 cm in width and depth were opened and filled with hydrogel prepared the day before and detailed in the following topic. The hydrogel used in the study, Prime Gel®, is marketed by company Tecnatti. According to technical specifications, on average, 1 kg of the product is capable of retaining up to 400 L of water in soils with good infiltration capacity.

Experimental design

The area was divided into nine plots with 36 m² each, in which the nucleation technique was applied. Species were chosen according to the floristic survey carried out by Bezerra (2009), opting for functional groups.

Thus, the Secretariat for the Environment of Ceará (SEMA) in partnership with the Botanical Garden of Ceará donated 180 seedlings of eight species found in the Caatinga required to carry out the study (Table 1). Each individual was tagged and had height and diameter at ground level (DGL) measured with the aid of measuring tape and caliper, respectively.

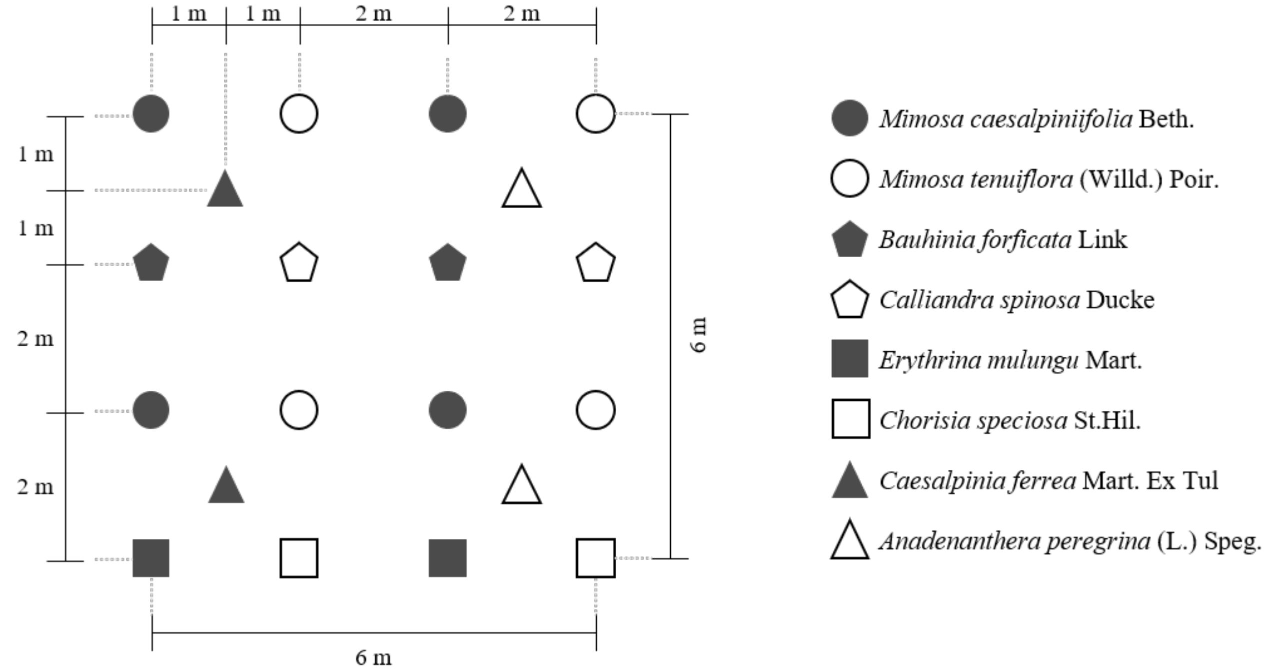
Table 1. List of species used and their respective functional groups

Popular name	Species	Family	Quantity	Functional group
Angico-Vermelho	*Anadenanthera peregrina* (L.) Speg.	Fabaceae	18	Climax
Jucá	*Caesalpinia ferrea* Mart. ex Tul	Fabaceae	18	Climax
Jurema-Preta	*Mimosa tenuiflora* (Willd.) Poir.	Fabaceae	36	Pioneer
Marizeira	*Calliandra spinosa* Ducke	Fabaceae	18	Pioneer
Mulungu	*Erythrina mulungu* Mart.	Fabaceae	18	Pioneer
Paineira	*Chorisia speciosa* St.Hil.	Bombacaceae	18	Pioneer
Pata de Vaca	*Bauhinia forficata* Link	Fabaceae	18	Pioneer
Sabiá	*Mimosa caesalpiniifolia* Beth.	Fabaceae	36	Pioneer

Inside nucleuses, the distance between ends was 2.0 m and the distance between the nucleus and diagonals was 1.4 m. Each plot contained 20 seedlings, distributed in four nucleuses, with *Caesalpinia ferrea* and *Anadenanthera peregrina* in the center of each nucleus (Figure 1).

Three treatments were carried out with three replicates (three plots) each. Each plot was 1.0 m away from the other and plots were randomly distributed for greater reliability of results. The first treatment (T1) consisted of the application of 1.0 kg of hydrogel/m² turned over with local soil and irrigation every day of the week. The same hydrogel dose was applied in the second treatment (T2), but with irrigation only 3 times a week. Finally, the last treatment (T3) received no hydrogel and irrigation was carried out every day of the week. This amount of hydrogel was defined from bibliographic surveys for soils with similar characteristics.

Figure 1. Experimental arrangement scheme applied to all plots



Throughout the experiment, irrigation was carried out semi-automatically, using a drip hose with holes every 2.0 meters between pioneer species, and every 4.0 meters between climax species (in the center), according to the planting scheme (Figure 1). Each hole had 2.0 mm in thickness, fixed to the hose wall, implying in practically zero losses. Early in the morning, hoses were turned on and water was lightly poured at the intersection of the stem and the root through holes on hoses that passed between individuals. After two hours on (by means of water accumulated in the crown with irrigation depth of approximately 20 mm, according to Navroski et al., (2015)), the irrigation system was interrupted.

Data collection

The growth of the plant community was evaluated through parameters plant height and stem diameter at the soil base, which were measured monthly for six months, performing an arithmetic mean of all individuals in each plot. To obtain basal area data, minimum and maximum height and diameter of the community and species, as well as to determine the relative dominance of species, the Fitopac 2 software was used (Shepherd, 2009).

The height and diameter growth for both community and species was calculated by subtracting the last measurement by the penultimate one from the parameter value, thus making an arithmetic mean in each plot. Subsequently, the distribution of individuals in diameter and height classes was temporally performed at intervals of 5 cm and 40 cm, respectively. For survival rates, both for community and species, the counting of which and how many individuals died during the experimental period was carried out.

To identify differences among treatments, all data for community and species were compared through analysis of variance (ANOVA), complemented by the Scott-Knott test, using the ASSISTAT software (Silva, 2010).

RESULTS AND DISCUSSION

Vertical structure

At community level, comparing the height growth in each treatment (Table 2), it was observed that, regardless of irrigation frequency, hydrogel application by itself was able to provide greater growth to plants in relation to plots that received no hydrogel application (even with daily irrigation). It was also observed that hydrogel application influenced the maximum heights found in the experiment, being approximately 90% higher and with no significant difference between irrigation frequencies. These facts are linked to water consumption, as the hydrogel gradually releases this resource to plants.

Table 2. Variables of initial growth of young plants submitted to hydrogel application with daily irrigation (T1), irrigation 3 times a week (T2) and only daily irrigation (T3), for six months.

Parameters	Unit	T1*	T2*	T3*
Minimum height	**cm**	30.00[a]	33.33[a]	30.00[a]
Average height	**cm**	103.50[a]	90.11[b]	69.04[c]
Maximum height	**cm**	209.00[a]	209.33[a]	114.00[b]
Height growth	**cm**	46.93[a]	46.06[a]	26.84[b]
Minimum Diameter	**cm**	0.61[a]	0.63[a]	0.40[a]
Average Diameter	**cm**	2.81[a]	2.87[a]	1.73[b]
Maximum Diameter	**cm**	6.63[a]	9.03[a]	4.92[a]
Diameter growth	**cm**	1.77[a]	2.38[a]	1.30[b]
Basal Area	**cm²**	0.0167[a]	0.0233[a]	0.0100[b]
Survival rate	**%**	96.53[a]	93.75[a]	88.89[b]

* For each parameter, means followed by different letters show significant differences.

However, the irrigation frequency was the predominant factor in the average height of the community. By irrigating every day, the community with hydrogel was able to present higher number of individuals with greater heights compared to irrigation frequency of only three times a week. These results corroborate studies by El-Hady and Wanas (2006), Galeş et al. (2016) and El-Asmar et al., (2017), who found that the presence of the hydrogel mixed with soil positively influenced the average plant height, with very significant differences compared to control.

By analyzing the average height over time (Table 3), from the third month, it is evident that hydrogel application was responsible for ensuring differences in height growth among treatments. However, only in the last month, irrigation frequency made difference, suggesting that in the long term, hydrogel application together with daily irrigation frequency is a strategy with better efficiency. Studies have shown that the positive effect of hydrogel on the average plant height is cumulative, which means that, at harvest time, differences in physical parameters between treatment and control were greater than those obtained during the vegetative stage or immediately after planting (Galeş et al., 2016).

Table 3. Monthly average height (cm) of young plants submitted to hydrogel application with daily irrigation (T1), irrigation 3 times a week (T2) and only daily irrigation (T3) for six months.

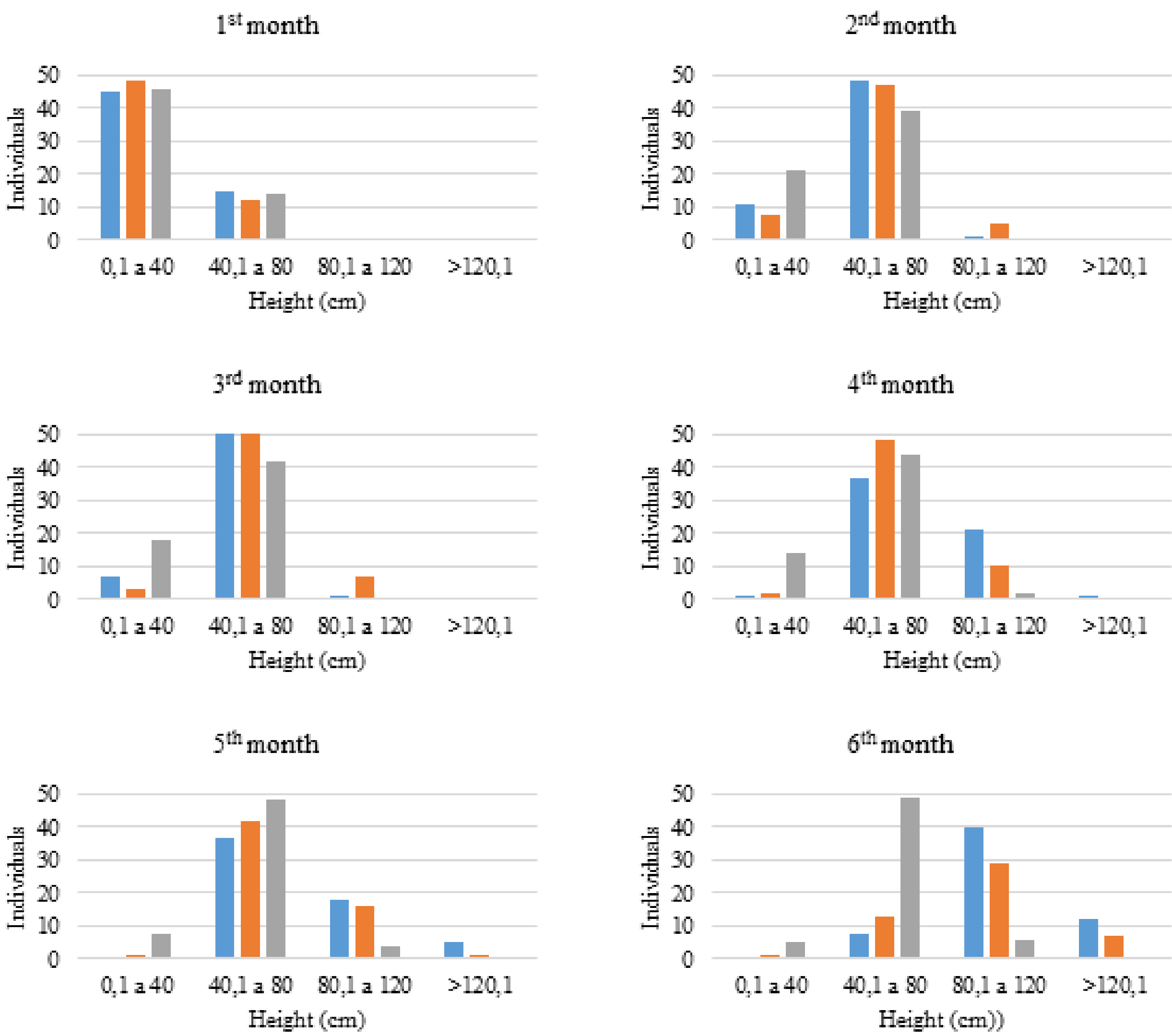
Treatment	Collection month *					
	1st month	2nd month	3rd month	4th month	5th month	6th month
T1	41.13[a]	51.07[a]	59.92[a]	79.58[a]	85.50[a]	98.50[a]
T2	54.40[a]	58.97[a]	60.02[a]	71.55[a]	73.83[a]	81.07[b]
T3	49.73[a]	50.68[a]	49.22[b]	54.17[b]	52.78[b]	54.98[c]

* Within columns, means followed by different letters show significant differences between treatments.

The results of this work regarding vertical structure have shown that, even with low water availability, hydrogel is a strategy that has positive impact on growth rate compared to the use of daily irrigation without hydrogel, being able to guarantee normal growth plant during periods of water scarcity, a fact that can often be decisive for crops.

Furthermore, it was observed that T1 contributed more to growth when observing the distribution of individuals in height classes over the six months of study (Figure 2). In the first measurement, in all treatments, individuals had the same average height, and when they presented greater height values, they were evenly distributed in treatments. From the second measurement, it was observed that the individuals with the greatest height values belong to treatments with hydrogel application, with T1 always presenting the best results for more developed individuals.

Figure 2. Height distribution of individuals submitted to hydrogel application with daily irrigation (T1), irrigation 3 times a week (T2) and only daily irrigation (T3) over six months.



It was observed that individuals in treatment without hydrogel (T3) were not able to reach heights greater than 120 cm. In T1 treatment, from the fourth month, individuals in this height class were observed. Although T1 and T3 received daily irrigation, this was expected due to the water retention capacity of the hydrogel. Furthermore, at the end of monitoring, most individuals in the hydrogel application treatments were in the height classes above 80.1 cm, while in the treatment without manipulation, most individuals belonged to the height class from 40.1 to 80 cm.

Horizontal structure

All diameter information is associated and partially corroborated with the hypotheses. At community level (Table 2), hydrogel application in the soil was not able to increase the minimum and maximum diameters of individuals. However, when compared to treatment with no hydrogel application, the use of hydrogel attributed higher values for average diameter and diameter growth rates, with no significant differences being observed from the reduction in irrigation frequency. The same was observed for basal area values, reflecting the diameter data obtained, since basal area corresponds to the relationship between diameter and occupied area. These results are similar to those obtained by Beniwal et al. (2010), in which hydrogel application to the soil favored low diameter growth, even so, larger than in cultures without manipulation. However, the authors pointed out that even with hydrogel application, if the irrigation frequency decreases, diameter tends to decrease.

Analyzing the average diameter during surveys (Table 4), as well as the vertical structure until the second month after hydrogel application, no significant difference in diameter among treatments was observed, which difference was evidenced only from the third month on. However, similar to behavior observed in height growth at the end of the experiment, no significant differences between irrigation frequencies after hydrogel application were observed.

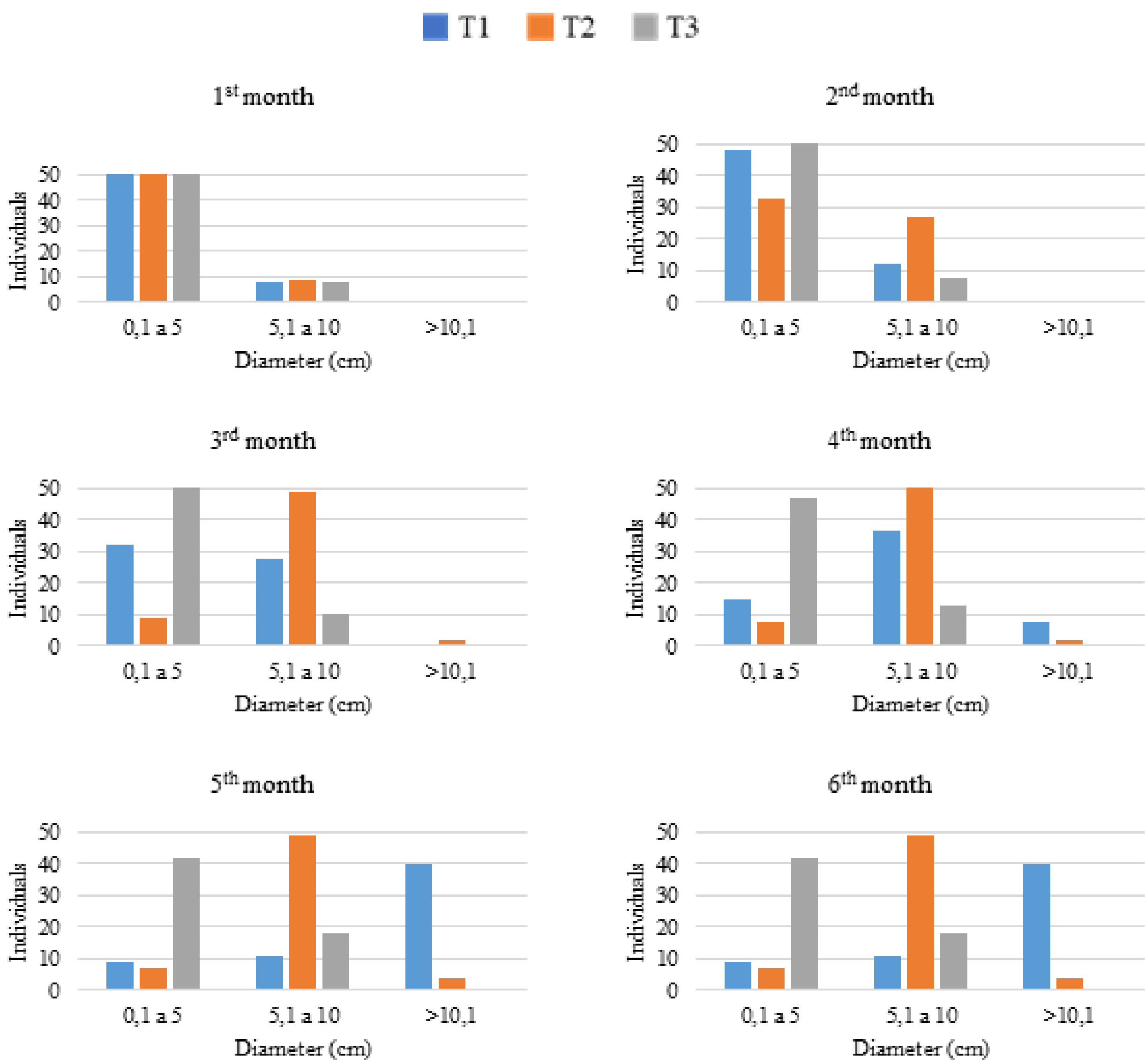
Table 4. Average monthly diameter (cm) of young plants submitted to hydrogel application with daily irrigation (T1), irrigation 3 times a week (T2) and only daily irrigation (T3) for six months.

Treatment	Collection month *					
	1st month	2nd month	3rd month	4th month	5th month	6th month
T1	41.13a	51.07a	59.92a	79.58a	85.50a	98.50a
T2	54.40a	58.97a	60.02a	71.55a	73.83a	81.07b
T3	49.73a	50.68a	49.22b	54.17b	52.78b	54.98c

* Within columns, means followed by different letters show significant differences between treatments.

The difference among the three treatments and the similarity between the two treatments with hydrogel application can be more explicitly observed when diameter classes are compared (Figure 3). It was found that in the second and third month of measurement, treatment with low irrigation frequency and hydrogel application was responsible for presenting individuals with larger diameters compared to treatment in which irrigation was more frequent.

Figure 3. Diameter distribution of individuals submitted to hydrogel application with daily irrigation (T1), irrigation 3 times a week (T2) and only daily irrigation (T3) over six months.



From the fourth month on, for both treatments with hydrogel application, a tendency to obtain uniformity in the quantitative distribution was observed. This fact corroborates studies by Faccioli et al. (2015), who pointed out that in tropical climates, species immediately assume survival strategies when there is low availability of resources. In this case, probably, individuals invested in functional attributes of diameter to store more resources.

In addition, it was observed that individuals in plots without hydrogel application (T3) did not invest in diameter but in height, since there was regularity in the number of individuals in this treatment in the first two classes throughout measurements. Rodríguez et al. (2013) and Liu et al. (2019) pointed out that in areas with few available resources, species tend to trade-off, that is, depending on environmental conditions, they choose to invest in height or diameter.

Finally, at the end of the experiment, almost all individuals belonging to T1 treatment were in the last class, with diameters above 10.1 cm, while in the other treatments, most T2 individuals presented diameter between 5.1 and 10 cm and T3 between 0.1 and 5 cm.

Thus, the greater presence of individuals of larger diameter classes contributes to the development of vegetation cover, avoiding water erosion and other types of degradation, being of paramount importance in areas under recovery. The vegetation cover is a natural defense, being a barrier of greater protection against the impact of rainwater, allowing better soil structuring (due to organic matter aggregation), and reducing surface water runoff (Almeida et al., 2018).

Community survival

It was found that hydrogel application favors the survival rate of individuals, with no significant differences from each other for this variable (Table 2). However, although there is no statistical difference with reduction in the irrigation frequency with the use of hydrogel, it was observed that greater water availability provided higher survival rates. Hydrogel prolongs the survival time of cultivated species by 90% (El-Asmar et al., 2017). This is justified by the fact that the water provided by the hydrogel increases the mobility of nutrients in the soil and makes them more readily available for plants (Bigot et al., 2013), since hydrogel polymers do not directly interact with soil matrices, but form aqueous gels with diameters in the range of centimeters that act as water reservoirs and facilitator of nutrient availability for the soil-plant system (Beniwal et al., 2010).

In terms of population (Table 5), it was found that the species whose functional group belonged to climax species (*Anadenanthera peregrina* and *Caesalpinia ferrea*) had their survival affected even in the presence of hydrogel. In addition to them, *Calliandra spinosa* also showed high mortality, possibly explained by the fact that this species is not native to the Caatinga (Santos and Romão, 2008), and even with hydrogel application, climax and non-native species present greater development difficulties (Ferreira et al., 2014; Savi et al., 2014).

Table 5. Survival rate (%) of seedlings submitted to hydrogel application with daily irrigation (T1), irrigation 3 times a week (T2) and only daily irrigation (T3) for six months.

Species	Treatment		
	T1	T2	T3
Anadenanthera peregrina (L.) Speg.	88.89	88.89	88.89
Caesalpinia ferrea Mart. ex Tul	94.44	88.89	66.67
Mimosa tenuiflora (Willd.) Poir.	100	100	100
Calliandra spinosa Ducke	88.89	72.22	61.11
Erythrina mulungu Mart.	100	100	94.44
Chorisia speciosa St.Hil.	100	100	100
Bauhinia forficata Link	100	100	100
Mimosa caesalpiniifolia Beth.	100	100	100

Although these species had the lowest survival rates, it was found that the incorporation of hydrogel and, more specifically, higher irrigation frequencies, increased their survival rate. Climax species need more resources to develop and generally show lower growth rates, especially in degraded areas where resource availability is limited (Silva et al., 2018).

All pioneer species had excellent survival percentages. According to Paul et al. (2010), pioneer rainforest species produce many small seeds that are widely dispersed and grow quickly, allowing them to compete with grasses and weeds, creating conditions that can favor the recruitment of other slower growing but shade tolerant rainforest species. Therefore, the use of hydrogel is an efficient strategy in the recovery of degraded areas, as it benefits the growth of pioneer species that will provide support for the development of climax species.

Thus, it was observed that hydrogel had a cumulative influence, and when combined with frequent irrigation, improved the growth of species.

In terms of height and diameter throughout the study period, it was only after the 3rd month that hydrogel application began to stand out in relation to treatment without manipulation. Furthermore, the combination of hydrogel application with irrigation frequency only started to differ from each other at the end of the experiment, suggesting that in the long term, water retention provided by the hydrogel brings advantages to the recovery process.

In environments with low availability of resources, species tend to trade-off, choosing to invest in specific characteristics so that they can develop properly. In all treatments, it was observed that populations preferred to invest more in height instead of diameter, behavior commonly found in semiarid species. However, the use of hydrogel has significantly contributed to increase the growth rate of the entire population.

The survival rate was about 8% higher in hydrogel treatment compared to treatment without manipulation. Furthermore, when compared to treatment without manipulation, the use of hydrogel favored the survival rate of climax species, although pioneer species managed to make better use of the availability of resources, resulting from the presence of hydrogel. Furthermore, for areas under recovery, it is important and necessary that pioneer species develop faster to support more selective species.

Therefore, the use of hydrogel associated with irrigation contributes to greater efficiency in the use of water resources and that its effects on pioneer and climax plants were effective as long as irrigation frequency management is carried out. Based on statistical tests used, with the application of hydrogel, the irrigation frequency in general is not a significant factor for the horizontal and vertical structural development of the population, suggesting that the use of hydrogel with reduction in the irrigation frequency would be a strategy as efficient as if irrigation was daily.

The aim of this work was to evaluate water absorption with the use of hydrogel, the amount of water used and the viability of hydrogel as a means to maintain the plant with greater absorption power for growth, but further works on this topic should analyze the soil characteristics and evaluate regeneration with other species and other irrigation frequencies.

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