Ambiente & Água - An Interdisciplinary Journal of Applied Science
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
E-mail: ambi.agua@gmail.com

Dalbergia nigra (Vell.) grown using hydrogel planting methods in the establishment of a silvopastoral system in a degraded soil

ARTICLES doi:10.4136/ambi-agua.2951

Received: 11 Aug. 2023; Accepted: 12 Jan. 2024

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ABSTRACT

This work tested the use of a superabsorbent polymer (hydrogel) in a silvopastoral system with Brazilian-rosewood (*Dalbergia nigra* (Vell.) Allemão ex Benth.) in a degraded pasture area. The experimental site is part of the Bananal do Norte experimental farm, Cachoeiro de Itapemirim, Espírito Santo, Brazil. Over 480 seedlings were planted and submitted to the treatments: Dry hydrogel (DRY); Hydrated hydrogel around the root ball (HAR); Hydrated hydrogel mixed with soil (HMS); and water only (WAT). The design was in randomized blocks, with three repetitions. The tested variables were plant survival, height and root collar diameter until 672 days after planting, soil moisture at 93 days after planting and total biomass and leaf chemical analysis at 184 days after planting. Survival was positively influenced by the application of the hydrogel, but there was little or no effect regarding the application method. The hydrogel and its application techniques did not alter growth in height and root collar diameter. The polymer did not influence the development in biomass and nutritional content of the leaves, but did influence the biomass distribution. The use of the superabsorbent polymer was therefore not effective in accelerating plant growth and anticipating the stages in the implantation of the silvopastoral system.

Keywords: agroforestry, brazilian-rosewood, degraded pasture.

Crescimento de *Dalbergia nigra* (Vell.) usando métodos de plantio de hidrogel no estabelecimento de um sistema silvipastoril em solo degradado

RESUMO

Neste trabalho, foi testado o uso de um polímero superabsorvente (hidrogel) em sistema silvipastoril com jacarandá-da-bahia (*Dalbergia nigra* (Vell.) Allemão ex Benth.), em área de pastagem degradada. A área experimental faz parte da fazenda experimental Bananal do Norte, Cachoeiro de Itapemirim, Espírito Santo, Brasil. Mais de 480 mudas foram plantadas e submetidas aos tratamentos Hidrogel seco (DRY); Hidrogel hidratado ao redor do torrão (HAR); Hidrogel hidratado misturado com solo (HMS); e apenas água (WAT). O delineamento foi em blocos casualizado, com três repetições. As variáveis testadas foram sobrevivência da planta, altura e diâmetro do coleto, até 672 dias após o plantio, umidade do solo aos 93 dias após o plantio e biomassa total e análise química foliar aos 184 dias após o plantio. A sobrevivência foi positivamente influenciada pela aplicação do hidrogel, mas pouca ou nenhuma diferença foi observada para os métodos de aplicação. O hidrogel e suas técnicas de aplicação não afetaram o crescimento em altura e diâmetro do coleto. O polímero não influenciou o desenvolvimento em biomassa e conteúdo nutricional das folhas, mas influenciou na distribuição de biomassa. Portanto, o uso do polímero superabsorvente não foi efetivo para acelerar o crescimento das plântulas e antecipar etapas na implantação de sistemas silvipastoris.

Palavras-chave: agroflorestal, jacaranda-da-bahia, pastagem degradada.

1. INTRODUCTION

Land degradation is defined as a process of decline or loss in biodiversity, ecosystem functions or services (Montanarella *et al.*, 2018). It is mainly human-caused, resulting in loss of biological productivity, ecological integrity and social values (Olsson *et al.*, 2019). Degraded lands have lost their original attributes, with the occurrence of poor and eroded soils, low stability, low resilience and lack of propagule sources, requiring interventions (Almeida, 2016). Changes in land use caused by agricultural, livestock and forestry activities have intensified over the years, leading to low sustainability in production models (Xie *et al.,* 2020). For example, the degradation of pastures in Brazil is a reflection of incorrect management in soil, plant or livestock (overgrazing, insufficient weed and pest controls, and lack of fertilization), resulting in the occurrence of eroded soils, with low fertility and high levels of soil compaction (Balbino *et al.,* 2011; Feltran-Barbieri and Féres, 2021).

Given the need to mitigate such impacts, agroforestry systems are an alternative to reconcile management practices combining trees, agricultural species and animals, which is similar to the natural environment in terms of diversity. Agroforestry differs from conventional systems, replacing intensive cultivation and monoculture practices with sustainable production (Ewert *et al.,* 2016). Among the models proposed by agroforestry systems, the silvopastoral system (SPS) is an alternative for the recovery of degraded pastures, providing productivity gains and alternative income for the farmers (Radomski and Ribaski, 2009). The use of native tree species improves such benefits; as conditioners of ecological succession, they promote a catalytic effect in environmental recovery through seed dispersal and fauna attraction (Moraes *et al.,* 2013).

A promising legume tree of great economic value for SPS is *Dalbergia nigra* (Vell.) Allemao ex Benth (Brazilian Rosewood), from the Fabaceae-papilionoideae botanical family. The recommendations for the species include the recovery of degraded areas and pasture afforestation (Gonçalves *et al.,* 2014). *D. nigra* is a species with a late secondary successional characteristic. It tolerates moderate shading rates and presents medium to fast growth. Its wood is very valuable, mostly used for the manufacture of luxury furniture and musical instruments (Carvalho, 1994). Despite the commercial value, it is an endangered species due to the process of deforestation of the Atlantic Forest, associated with global climate change, the absence of new plantations and low genetic diversity (Ribeiro *et al.*, 2011).

When it comes to SPS new plantations, especially with high-valued species, attention must be paid to the initial stages, because the area needs to be isolated from livestock in order to protect the seedlings before they are fully developed. The use of superabsorbent polymers (hydrogel) could be an option to accelerate this process, as their goal is to increase the water retention capacity in the soil, improve water use efficiency, reduce the frequency of irrigation and increase plants' initial development (Ekebafe *et al.*, 2011), avoiding losses and the need for replanting (Baggio *et al.*, 2009).

The use of hydrogel has been widely spread among forest plantings, as an alternative to overcome severe drought episodes driven by climate change in the tropics (Saha *et al.* 2020). Higher survival rates and satisfactory development have been achieved when using hydrogel in commercial plantings, especially for the *Eucalyptus* and *Pinus* species (Bartieres *et al.*, 2016; Mudhanganyi *et al*,. 2018; Felippe *et al*,. 2022). The product could also support seedling survival and growth in nurseries, meaning significant reduction in irrigation regimes (Navroski *et al.*, 2015).

However, the effects of hydrogels in the success of forest restoration plantings are not clear. While they may be efficient enhancing plant survival and plant water content in dryland restoration in Spain (Chirino *et al.*, 2011) or in *Cariniana pyriformis* seedling survival without irrigation in Colombia (Ríos *et al.*, 2021), both studies had observed little or no response for plant biomass. In southeastern Brazil, direct seeding of 14 native species was not affected by the use of hydrogel alone (Souza *et al.*, 2021), reaffirming the need for further investigation on the technical efficiency of hydrogels in forest plantings. The objective of this study was therefore to test the use of hydrogel and its application method, compared to traditional irrigation, in the establishment of a silvopastoral system with *D. nigra*. Our hypothesis is that the product might enhance the initial growth of native seedlings, in order to anticipate the entry of the animal component in the silvopastoral system.

2. MATERIAL AND METHODS

The work was carried out at the Bananal do Norte Experimental Farm, belonging to the Capixaba Institute for Research, Technical Assistance and Rural Extension - Incaper, in the district of Pacotuba, municipality of Cachoeiro de Itapemirim, Espírito Santo state, Brazil. It is located in the geographic coordinates of Latitude 20º44'49.66" S and Longitude 41º17'5.80" W, at 100 m above sea level (Figure 1). According to Köppen's classification, the climate of the region is classified as "Cwa", with dry winter and rainy summer (Alvares *et al.*, 2013).

The experimental area is located next to the Pacotuba National Forest and the Owned Nature Reserve Cafundó; together, they cover 968 hectares. The region, however, requires studies for biodiversity conservation, as little is known about its fauna and flora. In order to meet these needs, several studies were carried out in both Conservation Units. As an example, phytosociology (Abreu *et al.*, 2013; Archanjo *et al.*, 2012); nutrient cycling (Silva *et al.*, 2013; Godinho *et al.*, 2013a; Godinho *et al.*, 2014) and soil fertility (Godinho *et al.*, 2013b) are listed. Such studies are extremely important, as they serve as a reference for future comparisons on the progression of the ecological attributes of the Silvopastoral System. The choice of *D. nigra* was made based on the phytosociological studies carried out in the region, with great occurrence of the species and with potential use for silvopastoral systems.

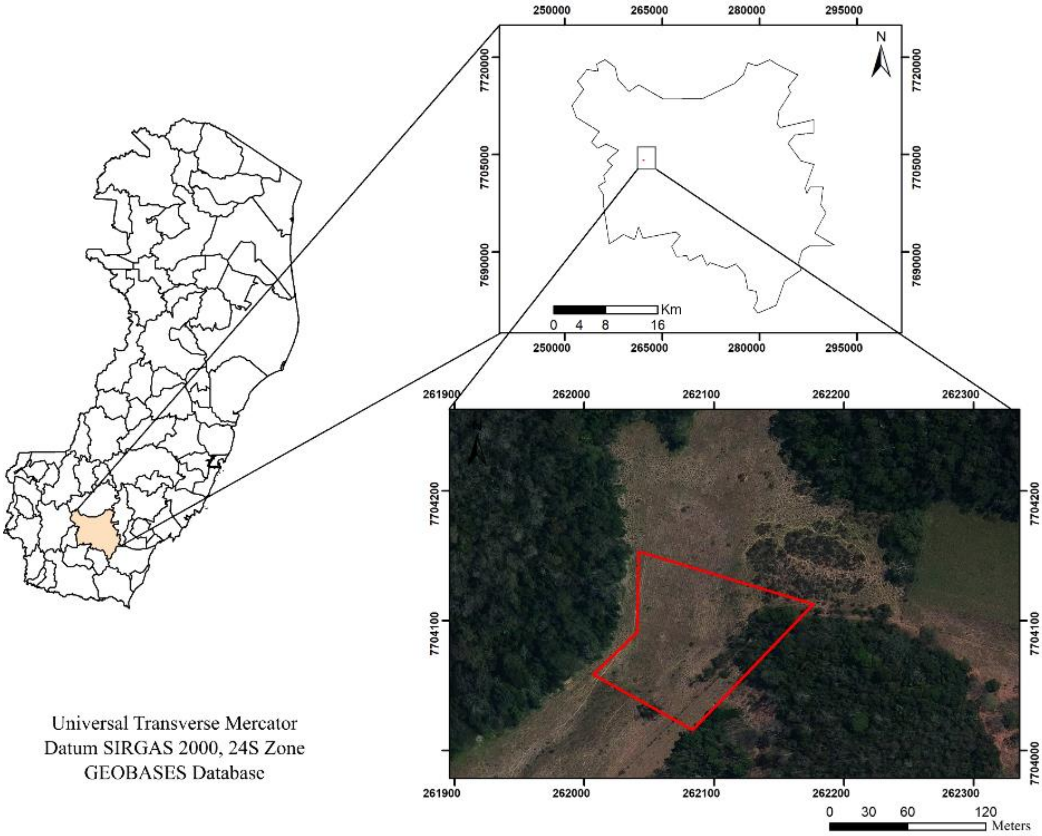

Figure 1. Study experimental area, Bananal do Norte Experimental Farm, Pacotuba, Cachoeiro de Itapemirim, ES, Brazil.

Soil samples were collected throughout the area, with the aid of a soil core sampler, at depths of 0 – 20 cm and 20 – 40 cm. The samples were dispatched to the soil laboratory of the Department of Forestry and Wood Sciences of the Federal University of Espírito Santo, for chemical and physical analysis (Table 1) and further soil fertility diagnosis.

Table 1. Chemical and physical soil properties in Bananal do Norte Experimental Farm, Brazil.

Soil parameter	Depth (m)	
	0 - 0,20	0,20 - 0,40
pH (H_2O)	5.3	5.4
Organic matter (g kg^{-1})	15.2	7.4
C (g kg^{-1})	8.8	4.3
P (mg dm^{-3})	1.0	1.0
K (mg dm^{-3})	29.0	16.0
Ca (Cmol dm^{-3})	2.2	1.9
Mg (Cmol dm^{-3})	0.8	0.6
Al (Cmol dm^{-3})	0.4	0.7
CEC (Cmol dm^{-3})	3.5	3.3
Clay (%)	52	55
Sand (%)	25	24
Silt (%)	23	21

Extraction methods: pH: 1:2,5 H_2O; P, K: Mehlich 1; Ca, Mg, Al: KCl-1mol L^{-1}; Organic matter: walklcy-black; Granulometry: Pipette method.

The site was mowed with the use of a tractor mounted rotary cutter to clear unwanted weeds and invasive plants. The soil was mechanically prepared, plowing and grading the experimental area. This procedure aimed to break the surface and subsurface layers of the soil, which were compacted by its previous use, as an overgrazed pasture. Subsequently, the planting rows were set six meters apart with subsoil tillage.

The mineral fertilization of the experiment consisted in the following nutrient doses: 50 g N, 40 g P_2O_5, 50 g KCl, 1 g B, 1 g Zn, 0.5 g Cu and 0.1 g Mo per plant, as recommended by Gonçalves (1995) for Brazilian native tree species standard fertilization. Phosphorus, nitrogen and micronutrients were applied aside from the planting pit (spot placement) and potassium chloride was placed on the surface, near the plants.

Ant control was performed with ant bait formicide, at a dosage of 10 $g.m^{-2}$. It started 60 days prior to the planting day and extended throughout the growth period, with periodic monitoring of the occurrence of ants. Three manual weed controls were carried out in the planting rows within the 180 days period. Moreover, mechanical mowing was performed between the planting rows, to allow the regeneration of brachiaria grass from the soil seed bank and the subsequent development of the silvopastoral system.

The seedlings were planted manually, two meters apart, composing the 6 m x 2 m spacing. Four treatments related to the application method of the superabsorbent polymer were tested, named: T1 - dry hydrogel (DRY); T2 - hydrated hydrogel around the root ball (HAR); T3 - hydrated hydrogel mixed with soil (HMS); T4 – water only (WAT). The dose of 5 g per plant was applied according to the manufacturer’s recommendation. DRY and OWA treatments required a rescue irrigation right after planting. All the treatments received three other irrigations, on the 7^{th}, 14^{th} and 29^{th} day after planting. This irrigation occurred due to the drought season and the absence of rains after the planting, avoiding plant withering.

The experiment was a randomized block design, with three blocks and four treatments. Each experimental unit was 20 x 24 meters, composed of four planting rows with 10 plants each, 40 trees per unit. In order to avoid the edges, the central portion of the experimental unit was sampled, with a total of 16 useful plants per plot. The total plant count of the experiment was 480, of which 192 were sampled (48 per treatment).

At 61 days after planting, the first inventory only measured the green or turgid seedlings, generating information on the number of dry seedlings due to water stress. At 93 days, a confirmation was made to see if there was regrowth or, in fact, death of the individuals. The mortality monitoring extended to further inventories and at the end of the evaluations the survival rate was calculated for each treatment. The Kaplan-Meier method was used to graphically represent the survival curve for the treatments and the curves compared by the log rank test (Bewick *et al.*, 2004).

The seedlings were evaluated for height, with measurements from ground level to apex, using a tape and, when necessary, a height measuring stick. The root collar diameter was also measured using the digital caliper. These measurements were intended to calculate the increase in height and root collar diameter as a response to the treatments at the end of the experiment. This evaluation was performed in the period of 61, 93, 126, 184, 247, 329, 490 and 672 days.

For biomass sampling, the seedlings were systematically picked, using the third seedling in the first row of each unit. If the plant presented any stress symptoms or abnormalities, it was replaced by the fourth seedling. Plants from the unit's borders were used to avoid interference in the mortality rate and the inventory performed of the useful plants. The biomass was collected 184 days after planting and the edge effect was not effective at the time.

With the aid of a saw, the plant was cut at root-collar height and separated into leaves, branches and stem. The root was also extracted to quantify root biomass. The material was stored in a thermal box and dispatched for analysis in the Forest laboratory of the Federal Institute of Espírito Santo (IFES – Ibatiba campus), in the municipality of Ibatiba, Espírito

Santo State, Brazil. The leaves went to a private laboratory in order to determine the contents of macronutrients and micronutrients. The material was placed separately in paper envelopes and submitted to drying in a forced ventilation oven, at a temperature of 80ºC, for quantification of the aerial biomass (MSPA) and root biomass (MSR) and total biomass (MST).

Biomass data was submitted to analysis of variance at 0.10 significance level and the residuals analyzed by Shapiro-Wilk normality test. If applicable, the means were compared by the Tukey Test. The 0.10 confidence level was used in order to capture lighter differentiations, according to interpretation of the dataset, especially for seminal seedlings. A p-value under 0.10 trends to statistical significance and could overcome random errors or small sample size problems (Thiese *et al.*, 2019).

Nonlinear regressions were adjusted to represent the growth in height and root-collar diameter over time, as nonlinear regressions are commonly used to represent biological growth patterns. With the aid of Curve Expert software, several regression models were adjusted and compared in terms of residual standard error and adjusted coefficient of determination. After ranking the best models, the Weibull regression model had the best performance (Equation 1). The model was used to represent growth in root-collar diameter and height.

$$Yi = \beta_0^{-} \beta_1 e^{-\beta 2 x \beta 3} + \varepsilon \quad (1)$$

In which: i= ith treatment; Y= Estimated height or root collar diameter; x = Days after planting; β= Model parameters; ε= Estimation error.

To evaluate the quality of the adjusted models, the residual standard error (Equations 2 and 3) and the adjusted coefficient of determination (Equation 4) were calculated, based on Terra *et al.* (2018).

$$\text{syx} = \frac{\sqrt{\sum (\text{ai-bi})^2}}{\text{n-p}} \quad (2)$$

$$syx(\%) = \left(\frac{syx}{c}\right) x\ 100 \quad (3)$$

$$R^2 aj = 1 - \left(\frac{n-1}{n-p}\right) x \left(\frac{SQ\ R}{SQ\ T}\right) \quad (4)$$

In which: i = ith measurement; syx = residual standard error (m, cm and %); R^2aj = adjusted coefficient of determination; a = actual height or diameter (m or cm); b = estimated height or diameter (m or cm); n = amount of data; P = number of estimated coefficients of the model; c = average actual volume or diameter (m or cm); SQR = sum of squares of the residues; SQT = sum of total squares.

3. RESULTS

The 672-day field survival data are shown in Figure 2. The curves were considered different by the log rank test (p = 0.01). Only HMS showed 100% survival, with the use of hydrated hydrogel mixed in the pit. The lowest survival rate was observed for WAT treatment, with only water.

Figure 3 shows rainfall data in 2017, in which September, the month after planting, there was no precipitation. The initial phase of planting requires greater water availability and the main goal of the hydrogel is to increase the water retaining capacity. Thus, it was expected that there would be lower mortality in the presence of the polymer.

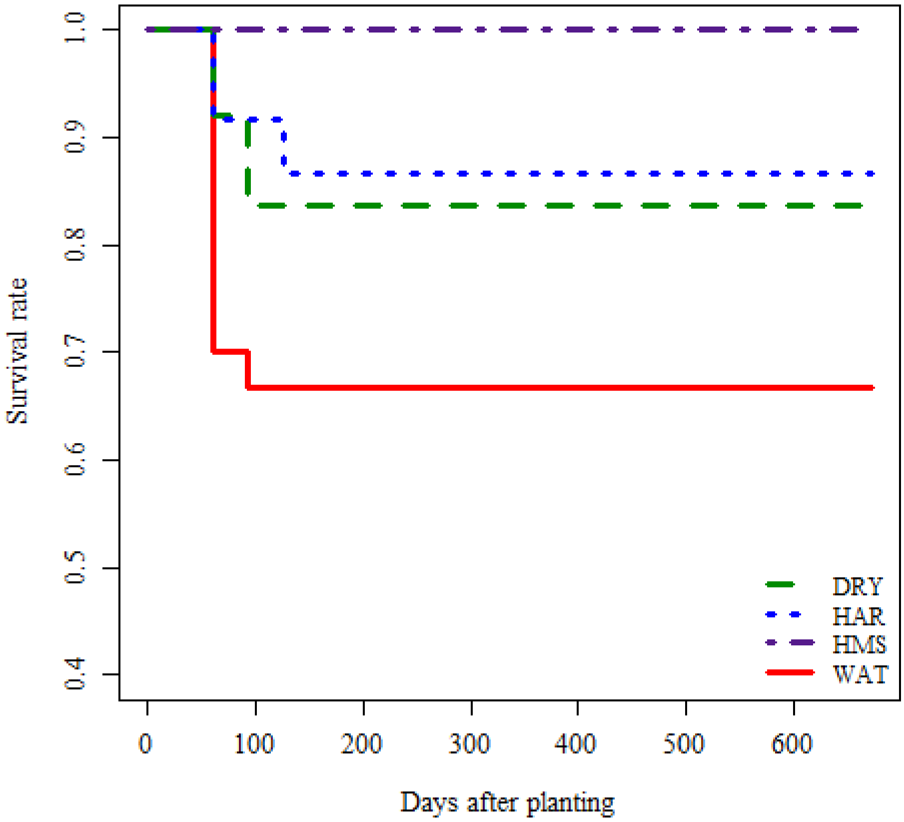

Figure 2. Kaplan-Meier survival curve for *Dalbergia nigra* 672 after planting for different hydrogel application methods. DRY: dry hydrogel; HAR: hydrated hydrogel around the root ball; HMS: hydrated hydrogel mixed with soil; WAT: water only.

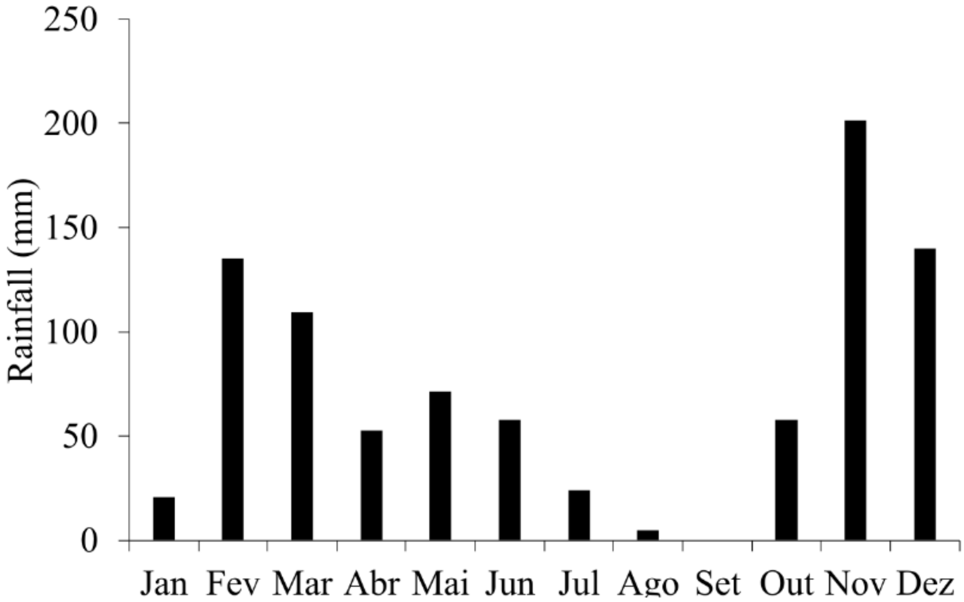

Figure 3. Rainfall data in Bananal do Norte Experimental Farm in 2017 (year of planting), measured by Incaper.

After adjusting the regression model, the confidence statistics of the model for height growth were calculated. Table 2 shows the coefficients and precision estimates for the Weibull model of height growth.

Table 2. Adjusted Coefficients and statistics for height growth data using the Weibull regression model for each treatment.

Treatments	Coefficients				Syx (%)	R^2
	b0	b1	b2	b3		
DRY	4.162488*	3.880290*	0.0000006 ns	2.400013*	0.2872	0.9991
HAR	3.869736*	3.664465*	0.0000047 ns	2.079865*	2.6568	0.9911
HMS	4.138369*	3.771201*	0.0000006 ns	2.403864*	0.0108	0.9931
WAT	4.185534*	3.871110*	0.0000003 ns	2.502253*	0.0844	0.9997

*Statistical significance by t test with 5% significance level. nsNon significant by t test with 5% significance level. R^2: Adjusted coefficient of determination; Syx: Residual standard error. DRY: dry hydrogel; HAR: hydrated hydrogel around the root ball; HMS: hydrated hydrogel mixed with soil; WAT: water only.

With the exception of the R^2 coefficient , all other coefficients were significant, by the t-test at 5% probability. A low residual standard error is observed, which proves that the adjusted regression estimates values very close to the observed values. The adjusted coefficient of determination is high, confirming the good quality of adjustment. The height growth curve (Figure 4) was estimated up to 672 days after planting and the estimated heights ranged from 3.85 m to 4.18 m for HAR and WAT, respectively. Therefore, the seedlings of *D. nigra* in the field did not exhibit any effects in height growth with the use of the polymer, because the treatment with absence of the product was superior to the others.

Among the treatments, only HAR with the hydrated hydrogel around the root ball had a lower estimated growth rate, in addition to a greater residual standard error. Therefore, among the application methods studied, HAR obtained the worst performance in height growth.

In this study, no growth effect was verified for the variables, presenting a similar estimated growth rate for all treatments, even in the absence of hydrogel. This factor may be related to the seed propagation method used in the seedling production, with the influence of different genetic material on the growth of the seedlings. Another fact that may have influenced the results is the mortality in experimental units without polymer use, which may have affected the mean height for WAT.

After adjusting the Weibull regression model, the regression coefficients adjusted for the root collar diameter data were calculated, as well as the statistics for each model (Table 3).

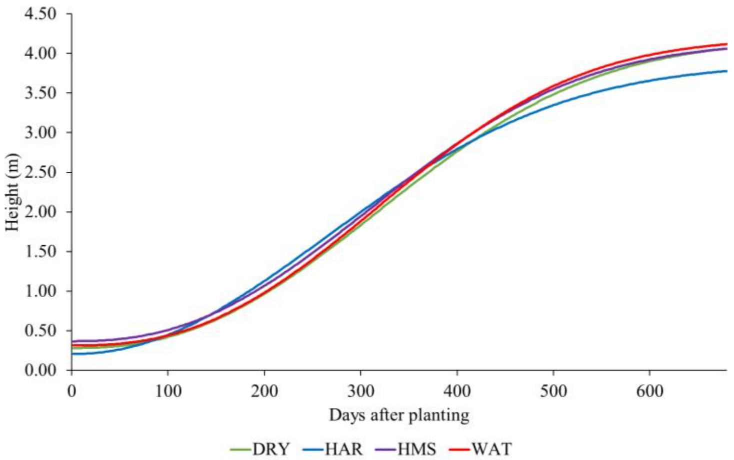

Figure 4. Growth in height over time using Weibull regression model for different hydrogel application methods. DRY: dry hydrogel; HAR: hydrated hydrogel around the root ball; HMS: hydrated hydrogel mixed with soil; WAT: water only.

Table 3. Adjusted Coefficients and statistics for root collar diameter growth data using Weibull regression model for each treatment.

Treatments	Coefficients				Syx (%)	R^2
	b0	b1	b2	b3		
DRY	6.452036*	5.913234*	0.0000001 ^{ns}	2.591529*	0.1200	0.9997
HAR	6.085894*	5.496745*	0.0000004 ^{ns}	2.444997*	0.0505	0.9999
HMS	7.331979*	6.875543*	0.0000060 ^{ns}	1.929724*	0.0005	0.9997
WAT	7.421099*	6.910131*	0.0000011 ^{ns}	2.192374*	0.0252	0.9999

*Statistical significance by t test with 5% significance level. ^{ns}Non significant by t test with 5% significance level. R^2: Adjusted coefficient of determination; Syx: Residual standard error. DRY: dry hydrogel; HAR: hydrated hydrogel around the root ball; HMS: hydrated hydrogel mixed with soil; WAT: water only.

As for the regression statistics, the residual standard error was low and the adjusted coefficient of determination was high for all the treatments, indicating good quality of the adjustment. Figure 5 shows the estimated regression curve for root collar growth up to 672 days. The diameters range from 6.05 cm to 6.99 cm for HAR and WAT, respectively. Neither height growth nor root collar growth was responsive to the use of the polymer.

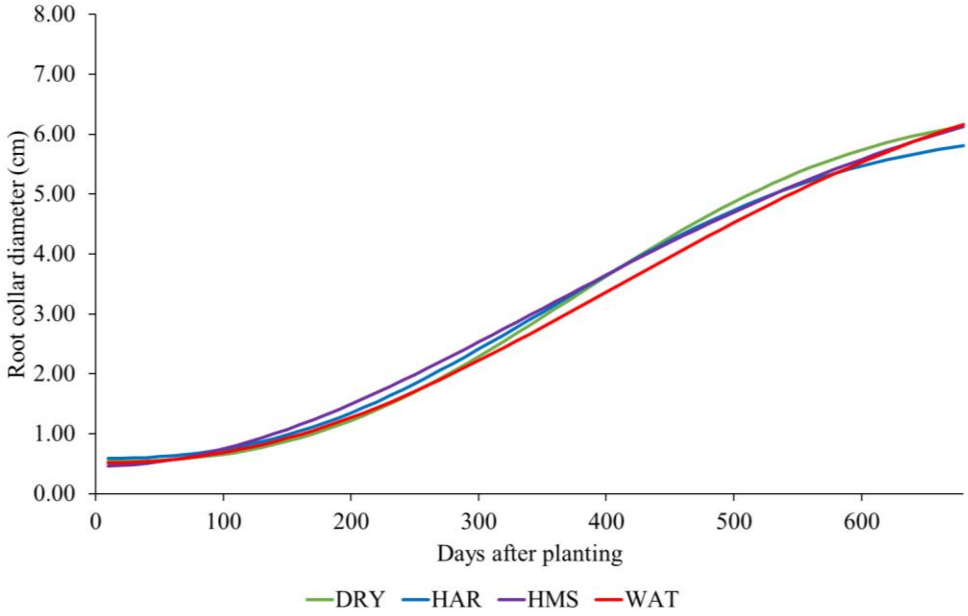

Figure 5. Growth in root collar diameter over time using Weibull regression model for different hydrogel application methods. DRY: dry hydrogel; HAR: hydrated hydrogel around the root ball; HMS: hydrated hydrogel mixed with soil; WAT: water only.

Table 4 shows data on the quantification of biomass performed at 184 days after planting. Only the shoot/root dry biomass ratio had a significant difference. However, in this study, there was no difference between treatments (P > 0.10) for the variables MSPA, MSR and MST. Evaluating the relationship between MSPA/MSR, there was a difference between treatments (P < 0.10) between the evaluated means, in which treatments with the use of polymer had lower values, indicating greater balance in plant architecture.

The contents of macro- and micronutrients found in the leaves of Jacarandá-da-Bahia are presented in Tables 5 and 6, respectively. There was no difference between treatments for the nutritional levels observed (P>0.10).

Table 4. Total and compartments of biomass of *D. nigra* 184 days after planting according to different hydrogel application methods.

Treatments	Dry matter (g)			
	MSR^{ns}	MSPA^{ns}	MST ^{ns}	MSPA/MSR*
DRY	22.49	48.36	70.86	2.15 ab
HAR	17.75	47.25	65.01	2.67 ab
HMS	15.14	22.67	37.83	1.48 b
WAT	14.38	41.40	55.78	3.01 a

Means followed by the same letter do not differ statistically by Tukey test with 10% significance level. ^{Ns}Non significant by F test with 10% significance level. MSR: Root dry biomass; MSPA: Shoot dry biomass; MST: Total dry biomass; and MSPA/MSR: Shoot and root ratio. DRY: dry hydrogel; HAR: hydrated hydrogel around the root ball; HMS: hydrated hydrogel mixed with soil; WAT: water only.

Table 5. Nutrient content, in g kg^{-1}, from *D. nigra* leaf chemical analysis according to different hydrogel application methods.

Treatments	N ^{ns}	P ^{ns}	K ^{ns}	Ca ^{ns}	Mg ^{ns}	S ^{ns}
DRY	41.77	1.30	18.63	8.50	4.77	0.67
HAR	45.60	2.03	19.30	7.93	4.70	0.80
HMS	43.53	1.87	13.40	9.23	5.43	0.77
WAT	43.30	1.63	30.87	9.67	5.37	0.70

^{ns}Non significant by F test with 10% significance level. DRY*:* dry hydrogel; HAR*:* hydrated hydrogel around the root ball; HMS*:* hydrated hydrogel mixed with soil; *WAT:* water only.

Table 6. Micronutrient content, in mg kg^{-1}, from *D. nigra* leaf chemical analysis according to different hydrogel application methods.

Treatments	Zn ^{ns}	Fe ^{ns}	Mn ^{ns}	Cu ^{ns}	B ^{ns}
DRY	41.77	1.30	18.63	8.50	4.77
HAR	45.60	2.03	19.30	7.93	4.70
HMS	43.53	1.87	13.40	9.23	5.43
WAT	43.30	1.63	30.87	9.67	5.37

^{ns}Non significant by F test with 10% significance level. DRY*:* dry hydrogel; HAR*:* hydrated hydrogel around the root ball; HMS*:* hydrated hydrogel mixed with soil; *WAT:* water only.

4. DISCUSSION

The root system has great importance in the initial planting period, being able to supply the water demand of the plant, preventing the adverse conditions from compromising survival rates (Marques *et al.*, 2013). For the species *Eucalyptus grandis* in seedling nurseries, similar studies did not determine significant effect for survival with the use of hydrogel (Saad *et al.*, 2009). However, the soil textural class influenced the mortality rate, which was higher in clay soil, just like the soil in the present study.

As the implantation was carried out during a dry period, it can be understood that, despite the rescue irrigations, the water retaining capacity of the soil was not greatly affected by the use of the polymer, especially by the fact that the soil has clayey texture. In the absence of moisture, as occurred in September, following planting, the hydrogel does not perform its retention function.

For exotic species, such as *Eucalyptus dunnii*, studies and literature has found significant gains in growth in seedling height under nursery conditions, with the use of hydrogel compared to the absence of polymer, as well as quadratic growth in response to the tested doses (Navroski *et al.*, 2015). For several Brazilian Cerrado species, such as *Dalbergia miscolobium*, Monteiro *et al.* (2016) observed no significant increase in height for treatments with the use of 400 ml of hydrogel in relation to the control treatment for seedlings eight months after planting in a degraded sandy soil. The result may have been influenced by soil fertility, which did not favor the development of the species.

In studies carried out using controlled-release fertilizers associated with hydrogel in the production of *D. nigra* seedlings, no influence on growth height was observed in the presence of the polymer (Cruz *et al.*, 2018). For native species in general, studies are not clear about the influence of hydrogel on growth variables.

Observing the growth curves, HAR with application of hydrated hydrogel around the root ball had the lowest tendency to estimate growth in root collar diameter, as well as for HMS, with hydrogel mixed in the pit. In the case of exotic species, the polymer provides an increase in diameter growth, as observed in the literature (Navroski *et al.*, 2015), with significant effects of hydrogel application in diameter growth for *E. dunnii*, which, however, at high doses, tends to decrease the growth means. For the native species *D. miscolobium*, there was a greater relative increase for the treatment without hydrogel application compared to the treatment with application of 400 ml of the polymer in the pit, eight months after planting, in a Brazilian Cerrado degraded sandy soil (Monteiro *et al.*, 2016).

Regarding the production of seedlings of *D. nigra* associating controlled-release fertilizers with hydrogels, another comparative study carried out by Cruz *et al.* (2018) did not find significant growth in root-collar diameter for the species, nor an increase in height. The greatest tendency to estimate growth in root collar diameter in the present study was attributed to WAT in the absence of the hydrogel polymer. This result indicates that the polymer did not influence the growth in root-collar diameter, in the given conditions. Genetic variability and soil conditions may have influenced the outcome of the experiment, as well as the mortality rate for WAT.

Studies evaluating the effect of mineral fertilization and liming on the growth and biomass of forest species are frequent and positive results are commonly observed. High values of MSR, MSPA and MST with limestone application as well as linear growth in biomass were observed in response to phosphorus doses, for *D. nigra* (Carlos *et al.*, 2018). Assuming that there is no influence of fertility in the treatments of this study, the use of the hydrogel polymer could be related to the growth in biomass.

The effect of hydrogel on exotic species such as *E. dunnii*, as carried out by Navroski *et al.* (2015), indicates that MSPA increases as the doses of hydrogel are increased. There is also a good response in MSR with the use of polymer, in addition to MST responses, increasing as a function of the dose. It is noticed that the results found by the authors were obtained in a greenhouse, with controlled conditions of temperature and humidity.

High values of the MSPA/MSR ratio are harmful to seedling growth, which may decrease the root absorption capacity and affect the seedling structure (Gomes *et al.*, 2013). The root development of seedlings is important for the plant to overcome adversities, such as the lack of nutrients and water (Reis *et al.*, 2012). In the present study, WAT, without hydrogel, had a high MSPA/MSR ratio, indicating that the use of the polymer affects the dry matter distribution between roots and shoots of the plants.

It is expected that the use of the polymer retains not only water, but also nutrients from fertilization, being gradually released to the plants (Bernardi *et al.*, 2012). The reduction in nutrient leaching consists of a decrease in fertilization and better absorption efficiency by plants. Nutrients are present in all parts of the plants. However, leaves are good indicators for changes in the availability of nutrients in the soil. Each species has an adequate level of nutrient in the leaves, from levels pre-established in the literature (Prezotti and Guarçoni 2013).

There are few studies for this species, as well as for most native species, with no recommended critical levels for each nutrient. A study by Carlos *et al.* (2014) presents nutrient content in the aerial part of *D. nigra* seedlings at 180 days, in which some nutrients had values similar to those seen in a treatment condition with complete mineral fertilization, such as phosphorus, calcium and magnesium. Nitrogen and potassium contents are higher in this study, while sulfur was lower than that observed by the compared study.

The contents of some micronutrients are similar to those found in the literature for the species *Dalbergia sissoo* at 24 months, such as zinc and iron (Singh and Bathi 2005). On the other hand, the copper content of the analysis is lower than that observed by the author above, and the manganese content is higher.

The main goal of hydrogel is to retain moisture in the soil for longer periods, making it available for the plant. However, some factors may influence the absorption of water by polymers. Clay soils, such as those in the present study, allow greater water retention in the soil, even without the application of hydrogel, and may have similar results (Mendonça *et al.*, 2015). The effects of polymer use are greater for sandy soils. Another factor that can influence the absorption capacity of polymers is the acidity and concentration of salts. For better absorption, a pH condition close to neutrality (pH = 7) and low saline concentration is desirable (Bogarim, unpublished data). By observing the soil analysis data presented in Table 1, it can be seen that these factors do not apply to the study.

The presence of salts and changes in pH are mainly influenced by chemical fertilization. Studies in the literature considered that water retention by superabsorbent polymers decreased in the presence of fertilizers and metal ions, and not all types of hydrogens were able to recover their retention capacity (Wang and Gregg, 1990). The base fertilization of the experiment may have influenced the retention capacity of the polymer.

5. CONCLUSIONS

Seedling survival was positively influenced by the application of the superabsorbent polymer. There was no influence of the use of polymer on height or diameter of the root collar, and the results were affected by the high genetic variability of the seedlings. The use of the polymer did not influence the development in biomass growth and leaf chemistry, but altered the biomass distribution. In these conditions, the use of the superabsorbent polymer for the species *Dalbergia nigra* is not recommended. The feasibility of using the product in plantations with *D. nigra* in degraded clay soils depends on research mainly related to the genetic improvement of the species and the behavior of hydrogel in clayey soils.

6. ACKNOWLEDGEMENTS

The authors would like to acknowledge the Institute of Research, Technical Assistance and Extension of Espírito Santo (Incaper) for the support and experimental area, the Research and Innovation Support Foundation of Espírito Santo (FAPES) and the National Council for Scientific and Technological Development (CNPq) for the financial support and the Federal Institute of Espírito Santo (IFES) for providing financial support for the translation of the manuscript and they have no conflict of interest to declare.

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