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Article

Efficiency of hydrogel and mulching in the survival and growth of *Guarea guidonia*

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Abstract - The current study assessed the efficiency of hydrogel and mulch in survival, height and diameter growth of *Guarea guidonia* (L.) Sleumer seedlings as technique for forest restoration of degraded areas. Four treatments were assessed in open site presenting exposed and compacted soil. Control treatment: only planting seedlings. Treatment 1: planting seedlings in plots exposed to hydrogel. Treatment 2: planting seedlings and depositing mulch around them. Treatment 3: planting seedlings in plots exposed to hydrogel and mulch depositing around seedlings. Using hydrogel in planting seedlings, mulch deposition around seedlings, or the combination of both, increase the survival rate and favors greater diameter and height growth in *G. guidonia* seedlings, as well as enhances forest restoration through seedling planting in degraded sites located in regions subject to water shortage.

Eficiência de hidrogel e cobertura morta na sobrevivência e crescimento de *Guarea guidonia*

Resumo - O presente estudo avaliou a eficiência de hidrogel e de cobertura morta na sobrevivência, crescimento em altura e em diâmetro de mudas de *Guarea guidonia* (L.) Sleumer como técnica de restauração florestal de áreas degradadas. Quatro tratamentos foram avaliados em campo aberto, apresentando solo exposto e compactado. Tratamento controle: plantio, de mudas. Tratamento 1: plantio de mudas em parcelas expostas ao hidrogel. Tratamento 2: plantio de mudas e aplicação de cobertura morta ao redor das mudas. Tratamento 3: plantio de mudas em parcelas expostas ao hidrogel e deposição de cobertura morta ao redor das mudas. O hidrogel utilizado no plantio de mudas, a deposição de cobertura morta ao redor das mudas, ou a combinação dos dois, aumenta a taxa de sobrevivência e favorece o maior crescimento em diâmetro e em altura das mudas de *G. guidonia*, além de potencializar a restauração florestal por meio do plantio de mudas em sítios degradados localizados em regiões sujeitas à escassez de água.

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Introduction

Forest restoration is very important where degraded ecosystems have lost their resilience and need human action for their reestablishment (Newton & Cantarello, 2015). Reforestation aims the return of ecological processes and regional biodiversity of previously existing forests (Martins, 2017), in addition to contributing to reducing climate change (Seabrook et al., 2011).

Forest restoration projects applied to degraded areas involving seedling planting techniques must have clear criteria for choosing the species to be used, in order to achieve objectives defined in project design and for the ecosystem undergoing restoration process to become self-sustainable and to dismiss future interventions (Brancalion et al., 2015). Seedling planting techniques are widely used due to their fast results in covering the site and in the succession processes. However, it is important to know the plants and ecological changes occurring in the sites in order to choose properly the species to be used (Martins, 2017).

Forest renovation based on seedlings aims at skipping the initial stages of natural succession, which comprise prior site colonization by herbs that will account for improving soil features due to the contribution from organic matter and for later allowing colonization by shrub-tree species (Pereira & Rodrigues, 2012).

The search for alternatives other than simple fertilization to get better survival rates and to the development of seedlings in forest restoration is important to reduce replanting costs and to achieve success in reforestation projects. Thus, hydrogel and mulching are highlight as technological strategies to aid restoring degraded environments (Piñeiro et al., 2013). Hydrogel, which is a soil moisture conditioner, helps water retention and availability for seedlings at their initial development stages (Hüttermann et al., 2009; Venturoli & Venturoli, 2011) by providing water availability for longer period, keeping seedlings hydrated even during longer droughts (Brancalion et al., 2015). Mulching provides increased rainwater retention (Piñeiro et al., 2013) and diminishes soil temperature amplitude in comparison to exposed soils (Pramanik et al., 2015).

The use of hydrogel along species belonging to genus *Eucalyptus* is well assessed and widely adopted (Buzetto et al., 2002; Felippe et al., 2016). However, studies using hydrogel in native species seedlings planted to restore degraded areas remain scarce (Venturoli & Venturoli, 2011; Coelho et al., 2018).

Guarea guidonia (L.) Sleumer, which belongs to family Meliaceae, stands out among species that have potential to forest restoration projects applied to degraded sites (Martins, 2014, 2017; Oliveira Neto et al., 2015). It is native to Brazil and has wide geographical distribution in the country; it is found in phytogeographic domains in Amazon, Caatinga, Cerrado and Atlantic Forest, but it is not endemic to Brazil (JBRJ, 2018). The species has arboreal habit, and it shows rapid growth and longevity that can reach 150 years (Oliveira et al., 2013). However, the species has different classifications regarding its ecological group, which ranges from pioneer (Azevedo et al., 2018) to late secondary (Martins, 2014, 2017; Corrêa et al., 2014). The species has zoochoric dispersal, which is a very important factor for wild fauna attractiveness (Noguchi et al., 2009).

The current experiment consists in planting *G. guidonia* seedlings in a degraded site, with and without hydrogel and mulching, in order to determine whether such strategies could influence seedlings' survival, and height and diameter growth. The hypothesis of the current research is that using hydrogel and mulching combined to seedling planting to restore degraded sites increases survival rates and enhances diameter and height growth of *G. guidonia* seedlings.

Material and methods

The current study was performed in Miraí (21°03'38"S and 42°33'26"W), Minas Gerais State, Southeastern Brazil, at altitude of 660 m above sea level. The research was developed in a degraded site belonging to Companhia Brasileira de Alumínio (CBA) presenting exposed and compacted soil.

The climate in the region is classified as Cwa according to Köppen classification: humid temperate climate with dry winter and hot summer (Sá Júnior et al., 2012). Mean annual temperature is 19 °C, with mean annual rainfall of 1,336 mm (Alvarez et al., 2013). During the period of the experiment (February 2014 to January 2016), the mean annual rainfall was 1,162 mm,according to data provided by Companhia Brasileira de Alumínio.

A completely randomized design (CRD) experiment, four treatments and five repetitions per treatment, was implemented in the open site presenting exposed and compacted soil. Each treatment consisted of a nucleus of four *Guarea guidonia* seedlings spaced one meter from each other in each nucleus (20 seedlings per treatment), and 3 x 2 m between nuclei. The control treatment (Tc) had only seedlings; treatment 1 (T1) had seedlings and hydrogel (absorbent polymer) in the plot; treatment 2 (T2) had seedlings with mulch deposited (vegetable remains) around them; and treatment 3 (T3) had seedlings, hydrogel in the plot and mulch deposition around the seedlings. Plots (0.40 x 0.40 x 0.40 m) were opened for seedling planting; fertilization was carried out in the plot treated with 125 g of NPK 10-30-10, in all treatments.

The hydrogel is composed of hydrophilic macromolecules formed by polyacrylamide, with high potential to retain and absorb water (Landis & Haase, 2012). It has the ability to make water available to the plant gradually (Brancalion et al., 2015). Hydrogel solution litter (1.5 g of hydrated powdered absorbent polymer for 1 L of water per plant) was mixed to each planting plot set for the treatments with hydrogel.

Soil samples were collected before treatments had started in the site; they were collected from the 0-20 cm and 20-40 cm layers and sent for chemical assessment at Viçosa Federal University's Soil Analysis Laboratory in order to check the site's degradation status.

The experiment was assessed every six months for two years to record *G. guidonia* seedlings' mortality rate, total height and diameter at ground level. Relative growth rate (RG) was determined through Equation 1 using height and diameter measurements at the time of planting and two years after it (Carneiro, 1995).

$$RG\ (\%) = \frac{\textit{Measure 2 years after planting - measure at planting}}{\textit{Measure at planting}} \times 100 \qquad (1)$$

Statistical assessment was subsequently performed through analysis of variance (ANOVA) and Duncan test (5% significance level) to check whether there was difference between treatments regarding mortality rate, increase in height and diameter, and relative growth rate. Kruskal-Wallis non-parametric test was used to assess initial height and relative height growth parameters, since they did not meet the predisposition for homoscedasticity and normality.

Regression adjustments were made to evaluate the association between time (months) and evaluated features (mortality, height and diameter at ground level) in each treatment.

Results

Soil analysis in the experimental site at the 0-20 cm and 20-40 cm layers showed low pH, low P level, high K level, low organic matter level, low exchangeable Ca and Al levels, medium exchangeable Mg level. The main differences were that at 0-20 cm it was observed mean cation exchange capability (CEC) (t) and CEC at pH 7, and low at 20-40 cm. At the deeper layer it was also noted high Al saturation and low base saturation index (Sobral et al., 2015).

The control treatment (Tc - only the seedlings) recorded the highest mortality rate one year after planting (55%) ($p < 0.05$) in comparison to the other treatments (5% each); however, there was no difference among treatments T1, T2 and T3 ($p > 0.05$) (Figures 1 and 2).

Table 1. Soil attribute values in sites used for *Guarea guidonia* seedlings planting.

Depth	pH	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	SB	t	T	V	m	P-rem	OM
cm	...	mg dm^{-3}		.... cmolc dm^{-3}						...... %		mg L^{-1}	dag kg^{-1}
0-20	5.23	8.7	61	1.18	0.59	0.3	1.93	2.23	6.23	31.0	13.5	23.0	1.79
20-40	4.73	3.1	65	0.43	0.19	0.8	0.79	1.59	4.59	17.2	50.3	20.3	0.9

pH: pH in water; SB: sum of exchangeable bases; t: effective cation exchange capacity; T: cation exchange capacity at pH 7.0; V: bases saturation index; m: Al saturation index; P-Rem: P remnant; OM: organic matter.

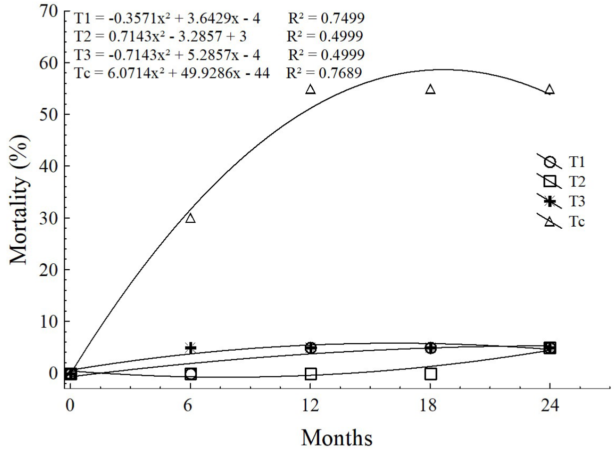

Figure 1. Mortality rate recorded for *Guarea guidonia* seedlings subjected to different treatments for 24 months. Tc: only seedlings; T1: seedlings and hydrogel (absorbent polymer) in the plot; T2: seedlings with mulch deposited (vegetable remains) around them; T3: seedlings with hydrogel in the plot and mulch deposition around them.

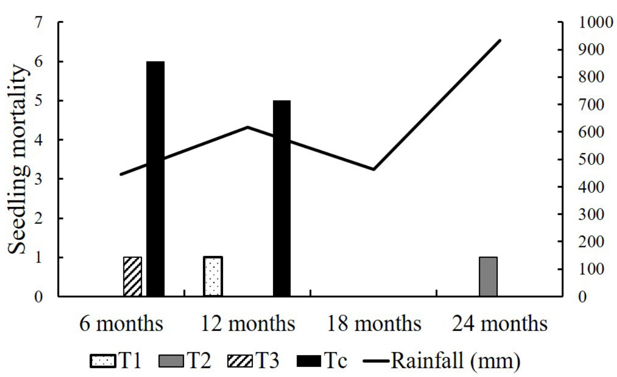

Figure 2. Number of dead *Guarea guidonia* individuals per treatment, at six-month intervals, with respective accumulated rainfall (Source: Companhia Brasileira de Alumínio - February 2014 to January 2016). Tc: only seedlings; T1: seedlings and hydrogel (absorbent polymer) in the plot; T2: seedlings with mulch deposited (vegetable remains) around them; T3: seedlings wih hydrogel in the plot and mulch deposition around them.

The period with greater rainfall provided the greatest increase in height and diameter in *Guarea guidonia* seedlings under all treatments - treatments with hydrogel have stood out (T1 and T3) (Figure 3).

Seedlings presented growth in height and in diameter at ground level, under all treatments, during the experiment. Growth was mainly in treatments based on hydrogel (T1 and T3), which led to higher values for these parameters (T2 and Tc) (Figure 4).

Treatments with hydrogel have reported greater increase in height ($p < 0.05$). However, there was no difference in relative height growth rates ($p > 0.05$) (Table 2). Difference was observed between treatments regarding increment and relative growth rate in diameter ($p < 0.05$) and treatments based on using hydrogel in planting plot recording the higher values (Table 3).

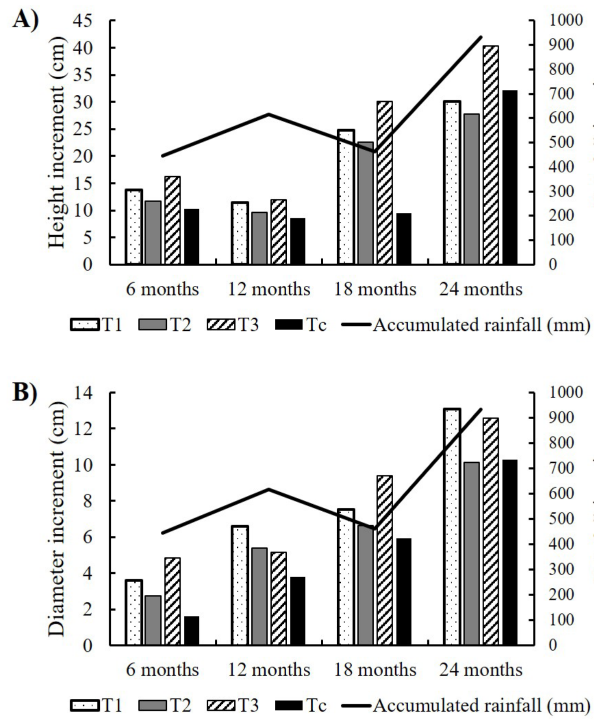

Figure 3. Mean height increment at ground level (A) and mean diameter increment at ground level (B) with respective accumulated rainfall (Source: Companhia Brasileira de Alumínio - February 2014 to January 2016) recorded for *Guarea guidonia* individuals subjected to different treatments (Tc: only seedlings; T1: seedlings and hydrogel (absorbent polymer) in the plot; T2: seedlings with mulch deposited (vegetable remains) around them; T3: seedlings with hydrogel in the plot and mulch deposition around them.

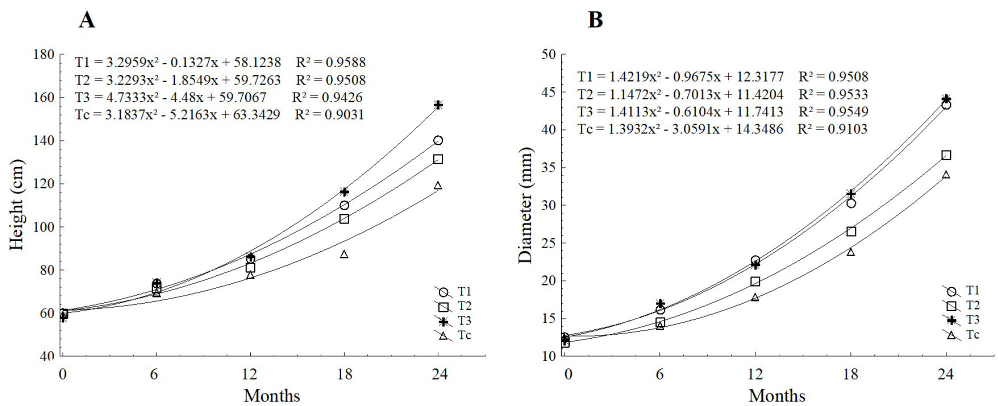

Figure 4. Mean height increment at ground level (A) and mean diameter increment at ground level (B) recorded for *Guarea guidonia* individuals subjected to different treatments for 24 months. Tc: only seedlings; T1: seedlings and hydrogel (absorbent polymer) in the plot; T2: seedlings with mulch deposited (vegetable remains) around them; T3: seedlings with hydrogel in the plot and mulch deposition around them.

Table 2. Initial final height, increments and relative growth in height of *Guarea guidonia* individuals under different treatments.

	IH (mm)	FH (mm)	Increment (cm)	RGH (%)
T1	60.1 ± 7.7 a	147.7 ± 35.1 a	87.6 ± 33.6 a	148.2 ± 61.9 a
T2	59.9 ± 6.3 a	121.7 ± 59.1 ab	75.2 ± 53.7 ab	130.9 ± 102.6 a
T3	58.5 ± 7.8 a	143.2 ± 59.4 a	88.1 ± 53.7 a	157.4 ± 101.6 a
Tc	59.5 ± 7.7 a	101.0 ± 50.9 b	48.7 ± 34.5 b	81.3 ± 52.1 a

FH and increment: Means with the same letter do not differ by the Duncan test ($p > 0.05$). IH and RGH: Means with the same letter do not differ by the Kruskal-Wallis test ($p > 0.05$). IH: average initial height (at planting); FH: final height (after two years of planting); RGH: relative growth in height; Tc: only seedlings; T1: seedlings and hydrogel (absorbent polymer) in the plot; T2: seedlings with mulch deposited (vegetable remains) around them; T3: seedlings, hydrogel in the plot and mulch deposition around the seedlings.

Table 3. Initial and final diameter at ground level, increments and relative growth in diameter of *Guarea guidonia* individuals under different treatments.

	DSLi (mm)	DSLf (mm)	Increment (cm)	RGD (%)
T1	12.7 ± 2.3 a	45.6 ± 10.4 a	32.9 ± 10.0 a	265.9 ± 90.3 a
T2	12.1 ± 2.3 a	36.1 ± 14.0 bc	24.9 ± 12.3 ab	217.7 ± 114.0 ab
T3	12.1 ± 2.2 a	41.7 ± 11.0 ab	29.6 ± 10.9 a	252.5 ± 103.3 a
Tc	12.3 ± 1.3 a	31.4 ± 12.2 c	19.1 ± 11.7 b	153.4 ± 84.5 b

Means with the same letter do not differ by the Duncan test ($p > 0.05$). DSLi: initial diameter at ground level (at planting); DSLf: final diameter at ground level (after two years of planting); RGD: relative growth in diameter; Tc: only seedlings; T1: seedlings and hydrogel (absorbent polymer) in the plot; T2: seedlings with mulch deposited (vegetable remains) around them; T3: seedlings, hydrogel in the plot and mulch deposition around the seedlings.

Discussion

Soil analysis from the site where the experiment was implemented before seedling planting showed low fertility (Table 1). The main attribute of soil analysis, namely: base saturation index (V), represents a general indicator of soil physical-chemical status, which encompasses several individual soil attributes (Kabala & Labaz, 2018). When the base saturation index is below 50%, it indicates low soil fertility (Sobral et al., 2015), a fact that can compromise the establishment and development of many plant species.

The use of hydrogel and mulching in plots have likely provided greater moisture retention in the soil and its gradual release to the seedlings. *Guarea guidonia* seedlings resisted water shortage, in the first months of the experiment (Figure 4). There was low rainfall in the first two months after seedling planting, as well as for six consecutive months after April 2014 (May to October 2014). Such a water shortage was enough to cause high seedling mortality under the control treatment (Tc) (Figure 3).

Venturoli & Venturoli (2011) assessed the effectiveness of hydrogel and reported 11% mortality seven months after the plantation of tree species to restore degraded sites in Cerrado Biome. According to these authors, initial mortality of tree species without hydrogel in the same study site was close to 20%. Another finding about the effectiveness of using hydrogel was mentioned by Viero & Little (2006). These authors mentioned that in an eucalyptus plantations subjected to suboptimal conditions in South Africa, hydrogel substantially increased seedlings' survival and initial growth.

Buzetto et al. (2002) did not observe differences regarding height in seedlings subjected to treatments without hydrogel and with the use of different hydrogel amounts in planting pits tested in post-planting *Eucalyptus urophylla* seedlings. However, the same authors found significant and positive results regarding seedling mortality decrease; they recorded 24.3% mortality under the treatment without hydrogel and 2.7% under the treatment based on the application of 0.8 L of pre-hydrated polymer solution (4 g of hydrogel dissolved in 5 L of water). Such solution was the best alternative for the greatest survival of *E. urophylla* seedlings in the field.

Pinus sylvestris seedlings showed greater increase in diameter when planting was carried out based on hydrogel (40% larger diameter in comparison to planting without hydrogel), as well as higher survival rate (68% with hydrogel and 20% without) one year after planting in a site in Slovakia for restoration purposes (Sarvaš et al., 2007).

Therefore, using hydrogel at seedling planting in forests, mainly in areas subjected to water shortage such as degraded sites, can enable increased survival and growth of forest species biomass (Orikiriza et al., 2013; Coelho et al., 2018), in addition to prove greater diameter and height increase (Akhter et al., 2004). It is important to highlight that increment in diameter and growth in height due to hydrogel in planting operations can change depending on each forest species. Thus, more research with other forest species and different hydrogel doses is needed.

Mulch deposition around the planted seedlings is also a viable and effective technique to retain moisture and protect against direct sunlight, wind and raindrops on the soil (Chalker-Scott, 2007), in addition to increase cationic exchange ability, soil nutrients and soil organic matter (Athy et al., 2006). Silva & Corrêa (2008) recorded better survival results for tree seedlings subjected to the treatment based on mulching over the planting plots than treatments without mulching in a mining site.

Water availability for plants is very important to their entire metabolic and physiological process, mainly at their initial growth and development stages (Navroski et al., 2016). Scalon et al. (2011) assessed different water regimes in initial growth stages of *Guazuma ulmifolia* Lam. seedlings and recorded lower seedling survival, growth in height and diameter, and lower relative growth rate in treatment based on less water availability (12.5% of the field capacity). They recorded the best values for these parameters under 50% and 100% availability of the field capacity. It is important to point out the role played by water availability in seedlings' initial growth and development stages in forest restoration projects. Good survival and initial growth rates recorded for seedlings, and consequent reduction in replanting costs and satisfactory soil coverage at shorter periods-of-time, are desired outcomes from restoration projects applied to degraded sites. Therefore, using hydrogel and mulching at forest species planting lead to higher seedling survival rates and to reduced costs with replanting and irrigation.

Conclusions

The use of hydrogel in planting plots, mulch deposition around seedlings or the combination of both methods increase the survival rate and favors greater diameter and height growth in *Guarea guidonia* seedlings. Thus, adopting these strategies can enhance forest restoration through seedling planting in degraded sites located in regions subject to water shortage.

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