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# Effect of Carnaúba Bagana Mulching on Tree Species Planted in Degraded Areas in Caatinga

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## Abstract

Experimental trials were conducted to evaluate the effectiveness of mulching with carnauba bagana, a by-product of wax extraction from *Copernicia prunifera* leaves, on the establishment of 32 shrub and tree species in the Caatinga region. The evaluations were made in areas degraded by mining and embankment of piçarra. Treated plants received 10 L of carnauba mulch in the crown of planted seedlings, while control plants received no mulch. After 24 months, mulching of carnauba improved the growth or survival of eight of the 32 species, while worsening that of two species. Specifically, mulching increased ($p<0.05$) the survival of *Pseudobombax marginatum* and *Peltophorum dubium*, and the height and canopy area of *Anadenanthera colubrina*, *Bauhinia cheilantha*, *Copernicia prunifera*, *Hymenaea courbaril*, *Mimosa caesalpiniifolia* and *Senna spectabilis*. The results demonstrate that the carnauba-based mulch can be directed to the species that responded positively, with the goal of improving establishment and growth in degraded areas of the region.

**Keywords:** Gravel mining, reforestation, land reclamation, semiarid, Vale do Açu, oil exploration.

## 1. INTRODUCTION AND OBJECTIVES

The State of Rio Grande do Norte (RN) is the largest producer of onshore petroleum in Brazil, with most activity concentrated in the semi-arid region under the domain of the Caatinga biome (ANP, 2020). However, petroleum extraction has specific and important environmental impacts, including the extraction of "piçarra". Piçarra is subsoil material composed of silt, sand and gravel used for embankment of pumpjack bases, drilling waste deposits, access roads, and other local structures used in the oil and gas industry. Piçarra extraction is carried out in several small open mines, each covering an area of approximately 2 hectares, with a depth of up to 15 meters (Resende & Chaer, 2021). In order to access piçarra, all vegetation and topsoil must be removed. After the exploration process, the mines, deposits, and the bases of decommissioned structures that have received piçarra undergo environmental recovery, which involves stages of landscape smoothing, soil decompaction, and the planting of native tree species, aimed at restoring the area's original vegetation (Resende & Chaer, 2010; Chaer & Resende, 2021; Lima et al., 2015a,b).

Restoring degraded areas in the Caatinga of the RN poses significant technical difficulties due to the region's unique challenges. Its characteristic semiarid climate presents long dry periods from June to January and rainy periods from February to March, ending between April and May (Ramalho et al., 2013). However, the seasonality of the torrential rainfalls is highly irregular, with varying start and end dates and uncertain durations from year to year (Gariglio et al., 2010). Additionally, the region's average annual precipitation is approximately 700 mm, but the occurrence of consecutive years with significantly lower volumes is common (Sobrinho et al., 2011). Compounding these challenges, high evapotranspiration rates due to the region's elevated temperatures throughout the year and high insolation rates are also common (Gomes, 2017). As a result, low and unpredictable water availability makes it challenging to establish native tree species in severely impacted areas of the Caatinga.The mulching technique offers a potential solution for increasing the successful establishment of plants in reforestation efforts for degraded areas, especially in semi-arid regions (Mconkey et al., 2012; Hueso-González et al., 2017; Coello et al. 2018). Mulching consists covering the soil around the newly planted seedlings with a thick layer of organic materialto to keep soil temperature adequate to plant growth, reduce water losses (Benigno et al., 2013; Jiménez et al., 2014; Gomes et al., 2009), control weed growth (Maggard *et al*., 2012), and provide nutrients for plants (Oliveira, 2017).

In the Potiguar basin, carnaúba bagana is a locally available material that can be used as mulch in environmental restoration plantations. This industrial organic residue is derived from the extraction of wax from the leaves of the carnaúba palm tree (*Copernicia prunifera* [Miller] H) (Ferreira et al., 2013; Silva et al., 2017). Farmers in regions where carnaúba wax is produced commonly use this residue due to its low-cost and efficient ground-covering properties (Queiroga et al., 2002). Additionally, carnaúba bagana has also been successfully used as mulch in vegetable plantations (Souza *et al*., 2016; Gomes et al., 2020), and in the composition of substrates for seedlings production (Sousa et al., 2012; Souza et al., 2015; 2016; Araújo et al., 2017; Albano et al., 2017; Silva et al., 2017).

Previous studies have shown positive results when carnaúba bagana was used as mulch in reforestation efforts. For example, Gonçalves et al. (2020) demonstrated that plants of *Vachellia farnesiana*, *Geoffroea spinosa*, and *Mimosa caesalpiniifolia* that received 10 L of carnaúba bagana as mulch had survival rates two to four times higher than the control group at 13 months after planting in a Sodic Saline Hydromorphic Vertisol area in Ceará state.

In a more recent study, Souza et al. (2022) explored the potential of carnauba bagana as a mulching material to facilitate the establishment of Caatinga trees in a piçarra mine located in Pendências, RN. The researchers examined the impact of bagana mulch on seedlings planted directly on the bare piçarra or after the application of a topsoil layer throughout the entire area. The findings indicated that the bagana mulch had a significant positive effect on the growth of most of the 15 tree species evaluated, particularly in the presence of a topsoil layer.

This study expands upon the previous research conducted by Souza et al. (2022) and Gonçalves et al. (2020) by examining the efficacy of carnaúba bagana mulching on a greater number of native species and in various degraded areas resulting from mining and piçarra utilization in Rio Grande do Norte, Brazil. A total of 32 Caatinga tree and shrub species were assessed across four decommissioned sites, comprising two piçarra mines, a pumpjack base, and a drilling waste deposit.

## 2. MATERIAL AND METHODS

### *2.1. Study area*

The study was conducted simultaneously in four decommissioned areas associated with onshore petroleum and natural gas exploration activities in the Potiguar Basin, State of Rio Grande do Norte, Brazil. Two areas refer to piçarra mines located in the municipalities of Pendências (J1 mine) and Assú (J2 mine).

The third area refers to a decommissioned pumpjack base (area where the drilling structures and, later, petroleum and gas pumping structures are assembled) located in Assú, RN. Pumpjack bases have an approximate area of 3000 $m^2$ where all vegetation is removed along with the topsoil. After earthworks in the area, a layer of piçarra is placed to raise the final elevation of the land in relation to the surroundings by approximately 30 cm.

The fourth area was a drilling waste deposit. These areas are normally old piçarra extraction pits that are waterproofed to receive contaminated material resulting from the drilling of wells, until removal for final treatment.

After the destination of the material, the tank is covered with layers of piçarra and is ready for revegetation. The chemical and physical characteristics of the existing substrate in each area are presented in Table 1. The substrate of all sites presented

**Table 1.** Chemical and physical characterization of the substrate (piçarra) of the four study areas in the municipalities of Assú and Pendências, RN, Brazil.

| Area* | pH | N | P | K | $Ca^2$+ | $Mg^2$+ | $Al^3$+ | H+AL | CTC | V | sand + silt | clay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | mg/L | | cmolc/dm³ | | | | | % | g/kg | |
| J1 mining site | 5.3 | 0.24 | 1.3 | 49 | 2.2 | 3.5 | 1.2 | 3.3 | 9.12 | 64 | 678 | 322 |
| J2 mining site | 7.0 | 0.22 | 8.9 | 140 | 6.0 | 1.9 | 0.0 | 0.0 | 8.26 | 100 | 792 | 208 |
| Waste deposit | 6.5 | 0.19 | 3.4 | 160 | 2.3 | 0.9 | 0.0 | 0.2 | 3.81 | 95 | 730 | 270 |
| Pumpjack base | 5.3 | 0.14 | 1.1 | 133 | 1.3 | 0.8 | 0.3 | 2.0 | 4.44 | 55 | 792 | 208 |

* pH in water; P (colorimetry), K (flame photometry), Ca and Mg (atomic absorption), Al (titration) and N (Kjeldahl), as described in Embrapa (1997).

a sandy clay loam or loam texture, low total N and high base saturation. The J2 mining site also presented a high content of labile inorganic phosphate.

## *2.2. Area preparation and seedling planting*

Before seedling planting, each area was fenced with seven strands of barbed wire to prevent the entry of domestic ruminants, especially goats. The substrate was decompacted using a subsoiler coupled to a crawler tractor. The subsoiling depth and furrow spacing were both, 50 cm. The planting holes (0.4 m by 0.4 m wide x 0.4 m deep) with the aid of an earth auger machine and manual articulated diggers. Each planting hole was fertilized with 50 g of simple superphosphate, 10 g of a micronutrient cocktail composed of Mo, B, Zn, Cu and Mn (FTE BR12) and 1.5 l of organic compost. It was also added in each planting hole 1.5 l of polyacrylamide-based planting gel previously hydrated (6 g/l).

Between 2017 and 2018, a total of 3,456 seedlings of 32 shrubs or trees, native or naturalized species to the Caatinga biome, were planted in two consecutive years according to the availability of seedlings (Table 2). The seedlings were produced in plastic bags and had a minimum height of 25 cm at the time of planting. Planting in 2017 was conducted at the end of the rainy season (July) and irrigation (7 l/plant) was necessary to ensure the establishment of the plants. This irrigation took place weekly in the first month after planting and biweekly throughout the second month after planting. In 2018, seedling planting was carried out in June, excepted for

**Table 2.** List of species and respective planting dates in four decommissioned areas associated with onshore petroleum and natural gas exploration activities in the Potiguar Basin, state of Rio Grande do Norte, Brazil.

| Species | Common name | Planting Date |
|---|---|---|
| *Amburana cearensis* (Allemão) A.C.Sm. | Cumaru | July/2017 |
| *Anacardium occidentale* L. | Cajueiro | July/2017 |
| *Anadenanthera colubrina* (Vell.) Brenan | Angico-vermelho | July/2017 |
| *Aspidosperma pyrifolium* Mart. & Zucc. | Pereiro | July/2017 |
| *Astronium urundeuva* (M.Allemão) Engl. | Aroeira | July/2017 |
| *Bauhinia cheilantha* (Bong.) Steud. | Mororó | July/2017 |
| *Cenostigma pyramidale* (Tul.) Gagnon & G.P.Lewis | Catingueira | July/2017 |
| *Cereus jamacaru* DC * | Mandacaru * | July/2018 |
| *Copernicia prunifera* (Mill.) H.E.Moore | Carnaúba | July/2018 |
| *Enterolobium timbouva* Mart. | Orelha-de-macaco | July/2017 |
| *Erythrina velutina* Willd. | Mulungu | July/2018 |
| *Guilandina bonduc* L. | Jucá-bonduc | July/2017 |
| *Handroanthus impetiginosus* (Mart. ex DC.) Mattos | Ipê-roxo | July/2017 |
| *Hymenaea courbaril* L. | Jatobá | July/2017 |
| *Jatropha curcas* L. | Pinhão-manso | July/2017 |
| *Libidibia ferrea* (Mart. ex Tul.) L.P.Queiroz | Pau-ferro | July/2017 |
| *Microdesmia rigida* (Benth.) Sothers & Prance | Oiticica | July/2017 |
| *Mimosa caesalpiniifolia* Benth. | Sabiá | July/2017 |
| *Mimosa laticifera* Rizzini & A.Mattos | Jurema-de-espinho | July/2017 |
| *Mimosa schomburgkii* Benth. | Monjoleiro | March/2018 |
| *Mimosa tenuiflora* (Willd.) Poir. | Jurema-preta | July/2017 |
| *Parkinsonia aculeata* L. | Turco | July/2018 |
| *Peltophorum dubium* (Spreng.) Taub. | Canafístula | July/2017 |
| *Piptadenia retusa* P.G.Ribeiro, Seigler & Ebinger | Jurema-branca | July/2017 |
| *Pityrocarpa moniliformis* (Benth.) Luckow & R.W.Jobson | Catanduva | July/2018 |
| *Pseudobombax marginatum* (A.St.-Hil., Juss. & Cambess.) A.Robyns | Embiratanha | July/2017 |
| *Sarcomphalus joazeiro* (Mart.) Hauenshild | Joazeiro | July/2018 |
| *Senegalia polyphylla* (DC.) Britton & Rose | Unha-de-gato | July/2017 |
| *Senna spectabilis* (DC.) H.S.Irwin & Barneby | Cássia-do-nordeste | July/2017 |
| *Spondias tuberosa* Arruda | Umbú | July/2017 |
| *Tabebuia aurea* (Silva Manso) Benth. & Hook.f. ex S.Moore | Caraibeira | July/2017 |
| *Triplaris gardneriana* Wedd. | Pajeú | July/2017 |

*Cactaceae

the Mimosa schomburgkii seedlings planted in March (Table 2), but no irrigation was deemed necessary.

### *2.3. Installation of experiments*

For each species, it was assembled one experimental trial. Each trial was set up in a randomized block design containing 2 treatments and four replications. Blocks corresponded to each of the areas selected for the study. Each block was delimited in an area of 18 m by 9 m where 27 individuals of a single species were planted in a spacing of 3 m by 2 m in three parallel lines containing nine plants each. In one of the lines, defined by chance, the treatment with carnauba bagana was applied, while the other two lines were kept as a control treatment, keeping the substrate without any covering. One third of the plants were chosen to receive the bagana treatment due to the limited availability of this material during the experiment's setup.

Carnauba bagana was applied 30 days after planting the seedlings in the field. Approximately 10 liters of the bagana were applied on the soil surface around each plant within a radius of approximately 25 cm (Figure 1). The contents of macro and micronutrients in the carnaúba bagana, obtained after nitro-perchloric digestion, are shown in Table 3.


**Figure 1.** Application of carnauba bagana (A) and detail after application (B). Piçarra J1 mining site in Pendências, RN, Brazil.

**Table 3.** Macro and micronutrient contents present in carnauba bagana.

| Ca | Mg | K | P | N | Fe | Mn | Cu | Zn | B |
|---|---|---|---|---|---|---|---|---|---|
| g kg-1 | | | | | mg kg-1 | | | | |
| 7.1 | 2.3 | 9.6 | 1.3 | 25 | 1320 | 115 | 11.2 | 29.3 | 51.8 |

## 2.4. Growth and survival of species

Plants were monitored (survival and growth) once a semester for 24 months. The first measurement was conducted in August 2017 or 2018, or April 2018, depending on the species, about 30 days after planting, when treatments were applied. Subsequent measurements were always conducted at the end of the dry (November to December) and the rainy seasons (May to June).

In each evaluation, height and plant survival were recorded, and in the last evaluation canopy area was also measured. The growth rate of the species in each treatment was calculated by the difference in height found in the last measurement and that of the first measurement, followed by the division by time in months between the measurements, being expressed in cm.month$^{-1}$ in a plot total basis. The canopy area of the plants was obtained by taking two measurements of the canopy diameter in perpendicular directions. To transform these measurements into m$^2$ of crown area, the ellipse formula was used, when both radii (m) are multiplied with each other and then by π. To obtain the survival rate (%) for each treatment, the respective numberof plants of each species that were still alive in each plot during the last field evaluation was counted, multiplied by 100 and divided by the respective number of planted seedlings.

## 2.5. Data analysis

The response variables growth rate, canopy area and percentage of survival for each species were evaluated through the analysis of variance (ANOVA technique), using mixed-effects models (MEM) (Zuur *et al.*, 2009): blocks and treatments were considered, respectively, to have random and fixed effects. For the explanatory variables, the block effect was considered as a random factor, while the treatment effects were considered as fixed factors in the structure of the evaluated models. The means of the variables, within each age, were compared by the F test ($p<0.05$). These analyzes were conducted in the R software (R Development Core Team, 2018), using the packages the lme4 (Bates, 2015) and lsmeans (Lenth, 2016).

## 3. RESULTS AND DISCUSSION

The application of carnauba bagana as mulch significantly influenced the height growth rates of nine of the 32 species evaluated. The growth rate in height of the species *Anadenanthera colubrina*, *Hymenaea courbaril* and *Senna spectabilis* were significantly higher with the application (3.85 cm.month$^{-1}$, 1.11 cm.month$^{-1}$ and 3.03 cm.month$^{-1}$, respectively) than without the application of carnauba bagana (2.32 cm.month$^{-1}$, 0.68 cm.month$^{-1}$ and 1.99 cm.month$^{-1}$, respectively) ($p<0.05$) (Table 4).

Seven of the analyzed species responded to the application of carnauba bagana when considering the crown area. Five of these responded positively (*A. colubrina, Bauhinia cheilantha, Copernicia prunifera, Mimosa caesalpiniifolia, S. spectabilis*) and two negatively (*Libidibia ferrea* and *Tabebuia aurea*)

**Table 4.** Height growth rate, canopy area and plant survival rate of 32 tree and shrub species at 24 months after planting in areas degraded by oil and gas exploration and production activities (Assú and Pendências, RN, Brazil). For each species and variable, the asterisks indicate a significant difference between treatments with and without carnauba mulch (F test; p<0.05). Legend: CB = carnauba bagana

| Species | Height growth rate (cm.month-1) | | Canopy area (m2) | | Plant survival (%) | |
|---|---|---|---|---|---|---|
| | With CB | Without CB | With CB | Without CB | With CB | Without CB |
| *A. cearensis* | 2.05 | 0.95 | 0.33 | 0.21 | 22 | 64 |
| *A. occidentale* | 3.67 | 4.34 | 1.00 | 1.38 | 25 | 25 |
| *A. colubrina* | 3.85* | 2.32 | 0.74* | 0.39 | 67 | 62 |
| *A. pyrifolium* | 1.67 | 1.34 | 0.23 | 0.21 | 78 | 87 |
| *A. urundeuva* | 1.68 | 1.78 | 0.62 | 0.93 | 94 | 75 |
| *B. cheilantha* | 1.65 | 1.63 | 0.27* | 0.23 | 28 | 25 |
| *C. pyramidale* | 1.77 | 1.63 | 0.45 | 0.51 | 72 | 68 |
| *C. jamacaru* | 4.27 | 4.57 | 0.00 | 0.13 | 81 | 68 |
| *C. prunifera* | 2.27 | 2.36 | 0.33* | 0.31 | 92 | 92 |
| *E. timbouva* | 4.78 | 4.81 | 1.10 | 0.89 | 97 | 92 |
| *E. velutina* | 2.97 | 2.41 | 0.52 | 0.72 | 22 | 18 |
| *G. bonduc* | 3.43 | 3.24 | 1.31 | 1.39 | 78 | 79 |
| *H. impetiginosus* | 3.63 | 2.78 | 0.54 | 0.42 | 96 | 96 |
| *H. courbaril* | 1.11* | 0.68 | 0.61 | 0.26 | 39 | 40 |
| *J. curcas* | 4.08 | 4.11 | 0.55 | 0.54 | 97 | 94 |
| *L. ferrea* | 4.10 | 4.31 | 1.04* | 1.70 | 81* | 96 |
| *M. rigida* | 4.82 | 3.70 | 1.09 | 0.94 | 56 | 69 |
| *M. caesalpiniifolia* | 8.36 | 8.12 | 7.71* | 6.06 | 94 | 100 |
| *M. laticifera* | 4.52 | 3.54 | 1.53 | 0.71 | 31 | 42 |
| *M. schomburgkii* | 8.45 | 8.38 | 3.00 | 4.10 | 89 | 100 |
| *M. tenuiflora* | 6.58 | 6.39 | 9.35 | 9.11 | 97 | 92 |
| *P. aculeata* | 3.48 | 4.39 | 1.41 | 2.37 | 78 | 81 |
| *P. dubium* | 6.23 | 5.10 | 0.79 | 0.76 | 65* | 30 |
| *P. retusa* | 5.03 | 5.28 | 4.10 | 4.60 | 78 | 83 |
| *P. moniliformis* | 6.34 | 4.31 | 1.75 | 0.94 | 41 | 56 |
| *P. marginatum* | 0.52 | 0.42 | - | - | 89* | 85 |
| *S. joazeiro* | 3.84 | 4.1 | 0.39 | 0.37 | 100 | 75 |
| *S. polyphylla* | 4.74 | 5.32 | 4.07 | 2.18 | 67 | 61 |
| *S. spectabilis* | 3.03* | 1.99 | 1.78* | 0.68 | 50 | 49 |
| *S. tuberosa* | 2.21 | 1.92 | 0.52 | 0.55 | 78 | 93 |
| *T. aurea* | 4.95 | 4.50 | 0.37* | 0.47 | 100 | 99 |
| *T. gardneriana* | 2.60 | 3.01 | 1.14 | 0.96 | 77 | 94 |
| Overall average | 3.83 | 3.55 | 1.57 | 1.45 | 70.6 | 71.6 |

(Table 4). *Anadenanthera colubrina* and *S. spectabilis* were the only species with the two growth measurements (crown area and height) positively influenced by the application of bagana.

Considering the 32 species studied, the average survival rate was 71% at 24 months after planting, regardless of carnauba bagana application (Table 4). However, the application of carnauba bagana significantly increased ($p<0.05$) the survival rate of *Peltophorum dubium* (from 30% to 65%) and *Pseudobombax marginatum* (from 85% to 89%), while it reduced that of *Libidibia ferrea* (from 96% to 81%).

The carnauba bagana is normally used as mulch and organic fertilizer for the carnauba trees themselves in Northeastern Brazil. Recent studies have demonstrated its viability in vegetable plantations (Souza et al., 2016; Gomes et al., 2020) and in the composition of substrates for the production of seedlings (Albano et al., 2017; Silva et al., 2017). The use of mulch has as one of the main benefits the reduction of water loss from the soil through evaporation, due to protection against direct insolation and reduction of soil temperature, important factors to promote plant development, especially in semi-arid regions such as the Brazilian Caatinga (Macêdo, 2007; Gomes et al., 2009; Silva et al., 2018). Carnauba bagana can also improve the physical soil structure and act as an organic fertilizer due to its high content of macronutrients (Sousa et al., 2015; Sousa et al., 2016; Araújo et al., 2017).

Despite the reported positive effects of the use of carnauba bagana as a mulching substrate, the results presented in this work indicate that these effects were limited on the set of 32 tree and shrub species evaluated. Only eight species (25% of the total) showed some positive response on growth or survival, and two showed negative response. Also, when the effects were significant, their magnitude was small, such as the observed for *B cheylantha*, *C. prunifera*, *M. caesalpiniifolia*, *P. marginatum* and *T. aurea*. Furthermore, the general averages of growth rate and survival, considering the set of 32 species, showed little variation between the two treatments (Table 4).

Several hypotheses can be raised to explore the reasons for the low response to mulch treatment under the conditions of this study. First, it can be argued that the amount of bagana applied as mulching was insufficient to bring the expected benefits. In this study, 10 L of bagana were distributed in a radius of approximately 25 cm (approximately 0.2 $m^2$) from the plant stem, which resulted in a layer of mulch approximately 14 cm thick. However, field observations showed that even after a few weeks after a rainfall event, when manually removing the mulch at the base of the plants, the substrate was moist, unlike the treatment without mulch. Therefore, we believe it is unlikely that the low response to mulch observed is related to the amount of bagana applied in the treatments. This observation is supported by the study by Gonçalves et al. (2020), where 10 L of carnauba bagana were also applied as mulch in three native species of the Caatinga in an area of Sodic Saline Hydromorphic Vertisol in the state of Ceará. In that study, the survival of *Vachellia farnesiana*, *Geoffroea spinosa* and *M. caesalpiniifolia* plants that received the mulch was two to four times higher than the control at 13 months after planting, showing the sufficiency of the volume of bagana used.

One can also question about the decomposition of the bagana and consequent loss of its mulching effect. To assess this possibility, we will take as reference the study by Oliveira (2017), which studied the dynamics of carnauba bagana decomposition in a semiarid environment in the state of Ceará using litterbags. This author showed that the half-life of carbaúba bagana was 345 days when the litterbags were placed in an area that received weekly irrigation during the 90 days of evaluation. Therefore, it is reasonable to assume that the half-life observed by Oliveira (2017) is shorter than under natural conditions in the field, where the soil remains dry (absence of precipitation) for approximately 8 months of the year. In addition, carnauba bagana has low biodegradability due to its high lignin content (Gomes et al., 2009) and residual wax components, such as acid and hydroacid esters, which limit the dehydration and hydration of the material, consequently protecting it from decomposition (Villa Lobos-Hernández & Muller-Goyman, 2005). Therefore, although in the present study we did not measure the residual mass of the bagana at 24 months after application, we estimate that the loss of mulch mass was small and insufficient for it to lose the mulching effect. This estimate is also supported by the visual observation conducted during field assessments.

Another factor that could influence the growth and survival rate of the species under the conditions of this study refers to the topographic conformation of the deposits, artificially lowered in relation to their surroundings. This condition can provide a greater accumulation of rainwater and, consequently, of soil moisture compared to the natural condition, a fact that could minimize the benefit provided by the mulch. In fact, piçarra deposits tend to accumulate rainwater and form small ponds during the rainy season, which tend to dry up during the dry season (Resende & Chaer, 2010). However, the pumpjack base and the drilling waste deposit areas do not show the topographic lowering as in deposits J1 and J2. As the response pattern of species to treatment with carnauba bagana was similar between areas (absence of block effect), we understand that the topographic factor also does not explain the low response to treatment.

Another hypothesis for the low response to the application of mulch with carnauba bagana under the conditions of this study may be associated to the application of 1.5 L of hydrated planting gel for both treatments in the planting hole, which may have alleviated the water stress in the dry season. It is also important to mention that the studied species have developed natural mechanisms to resist to the adverse conditions of heat and drought in the Caatinga (Angelim et al., 2007; Silva et al., 2014; Golçalves et al., 2019). Caatinga tree species present morphological and physiological adaptations that make them resistant to water deficit. The most common refers to the total or partial loss of leaves during the dry season, which limits the loss of water through evaporation during the dry season of the year. Other species are capable of producing specific anatomical structures to support the water deficit, such as the storage of water and nutrients in the green parts of cacti, such as the mandacaru (*C. jamacaru*), or in the xylopodia present in the roots of angico-vermelho (*A. colubrina*), cumaru (*Amburana cearensis*) and umbu (*S. tuberosa*) (Cavalcanti & Resende, 2006; Ramos et al., 2004).

Most species that did not respond to the carnauba mulching are fast-growing nitrogen-fixing legumes, such as *E. timbouva*, *M. caesalpiniifolia, M. laticifera, M. schomburgkii, M. tenuiflora* and *P. retusa*. Fast-growing arboreal legumes capable of forming symbioses with rhizobia and mycorrhizal fungi have been widely used in the recovery of degraded areas due to their high adaptability and biomass production capacity, even in areas were the topsoil was removed (Franco & de Faria, 1997; Chaer et al., 2011). Due to these characteristics, these species may be indifferent to the improvements in substrate conditions provided by the application of mulch in the studied environments.

A few studies have evaluated the effect of mulch on the growth of native tree species in reforestation. In a study conducted by Pimentel & Guerra (2015) in Quixeramobim, Sertão Central of the state of Ceará, Brazil, no effects of the application of litter-based mulch on the growth and production of leaves of cumaru (*A. cearensis*) were found after 365 days of planting of seedlings in an agroforestry system. Gonçalves et al. (2018) compared the use of carboard mulching under the crown of 11 native species in the Atlantic Forest to the conventional crowning (hoe), and concluded that mulching did not affect growth, but controlled weed competition and increased survival rate of two species. Although these studies were developed with mulch using different materials and environments, the results are in line with those observed in this work.

A recent study conducted by Souza et al. (2022) at the same J1 mining site as this study found that the mulch of carnaúba bagana did not improve the survival and growth of 15 native tree species. However, when combined with an 8 cm layer of topsoil applied across the total area, the bagana mulch enhanced the growth of the tree species, indicating a positive interaction between these factors. Furthermore, the presence of topsoil led to an abundant regeneration of herbaceous species, which helped to cover the soil during rainy seasons. This suggests that the bagana mulch may have reduced competition between tree seedlings and the vigorous herbaceous vegetation, promoting their growth and survival.

Despite the low response of the 32 species evaluated to the application of carnauba bagana mulch, it is notorious that a few species responded intensely and positively to this treatment, such as *A. colubrina*, *H. courbaril* and *S. spectabilis*.

Thus, the use of carnauba bagana can be directed directed to these species when they are used in forest restoration projects in the biome. This fact also shows the importance of conducting similar studies with other native species, in order to better understand the potential of using carnauba bagana in the recovery of degraded areas in the Caatinga.

## 4. CONCLUSIONS

Of a total of 32 native and naturalized Caatinga tree and shrub species evaluated in this study, 24 (75%) did not responded to the application of carnauba mulch after 24 months of planting. Only *Anadenanthera colubrina*, *Hymenaea courbaril* and *Senna spectabilis* showed a significant and strong positive high magnitude of positive response in terms of growth and/or survival rates. Therefore, the results of this study indicate that the use of mulch with carnauba bagana should be prioritized to these species in mixed species reforestation in areas degraded by piçarra exploration and deposition in the Caatinga biome.

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