




Article

Organic Mulching Alters the Soil Microclimate, Increases Survival and Growth of Tree Seedlings in Restoration Planting

Deivid Lopes Machado ^{1,*}, Murilo Nicolau Dourado ¹, Micael Silva de Freitas ¹, Letícia Moreira de Souza ¹, Eder Marcos da Silva ¹, Diego Sotó Podadera ², Carlos Rogério Andrade ¹, Wendy Carniello Ferreira ¹ and Frederico Augusto Guimarães Guilherme ³

¹ Instituto de Ciências Agrárias, Universidade Federal de Jataí, Jataí 75801-615, Goiás, Brazil; murilo.douradoo@gmail.com (M.N.D.); micaelfreitassilva@gmail.com (M.S.d.F.); moreira-flor@hotmail.com (L.M.d.S.); edermarcos@ufj.edu.br (E.M.d.S.); carlos_rogerio_andrade@ufj.edu.br (C.R.A.); wendy@ufj.edu.br (W.C.F.)

² School of Agricultural Sciences, São Paulo State University (UNESP), Botucatu 18610-034, São Paulo, Brazil; diego.podadera@unesp.br

³ Instituto de Biotecnologia, Universidade Federal de Jataí, Jataí 75801-615, Goiás, Brazil; fredericoagg@ufj.edu.br

* Correspondence: deivid.machado@ufj.edu.br; Tel.: +55-(64)-3606-8300

Abstract: Organic mulching has been suggested as an option for managing spontaneous species in restoration plantings and can promote improvements in soil properties and performance of planted species. The aim of this study was to test the effect of crowning techniques on soil microclimatic and performance of forest seedlings. The experiment was carried out in Goiás state, Brazil. Two study factors were used: crowning techniques (manual weeding, cardboard, wood chipping and control—without weed competition management), and six tree species: *Anadenanthera peregrina*, *Ceiba speciosa*, *Dipteryx alata*, *Inga edulis*, *Genipa americana* and *Spondias mombin*. Soil temperature and moisture assessments were performed within the crowning area (0.25 m²). Seedling survival and growth in height and diameter were evaluated over 219 days. Organic mulching treatments of wood chipping and cardboard provided increase in soil moisture and decrease in temperature, resulting in higher seedling survival rate. The increase in height and diameter differed among species under study, with *A. peregrina* standing out in height and *C. speciosa* in diameter. The crowning techniques did not influence the average height of species; however, wood chipping provided greater diameter increase. The findings of this study indicate that mulching treatments, by contributing to increase soil moisture and decrease soil temperature, can be used as crowning techniques to increase the survival rate and diameter growth of tree species in restoration plantings.

Keywords: ecological restoration; weed competition; wood chips; soil moisture; seedling performance



Citation: Machado, D.L.; Dourado, M.N.; de Freitas, M.S.; de Souza, L.M.; da Silva, E.M.; Podadera, D.S.; Andrade, C.R.; Ferreira, W.C.; Guilherme, F.A.G. Organic Mulching Alters the Soil Microclimate, Increases Survival and Growth of Tree Seedlings in Restoration Planting. *Forests* **2024**, *15*, 1777. <https://doi.org/10.3390/f15101777>

Academic Editors: Choonsig Kim and Lei Deng

Received: 3 September 2024

Revised: 3 October 2024

Accepted: 6 October 2024

Published: 10 October 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The Brazilian Cerrado is the second largest biogeographic domain of the country, occupying approximately 23% of the national territory [1]. Due to its high biodiversity [2] and current state of degradation, having lost more than 50% of its original coverage resulting from the advance of the agricultural and extensive farming frontier [3,4], it is considered one of the 25 global hotspots for conservation [5]. In addition to its ecological relevance, the Cerrado provides important ecosystem services, mainly in terms of water production and distribution [6]; nevertheless, it continues to be neglected both from the point of view of its conservation and projects aimed at its restoration.

Currently, one of the major bottlenecks for the restoration of Cerrado areas is weed competition with invasive exotic grasses [7], especially those of the genus *Urochloa* spp. introduced in Brazil for the formation of pastures [8]. These species exhibit significant adaptations to prevailing over conditions of elevated sunlight radiation and temperature, and have enhanced capabilities for the absorption and conversion of sunlight, water and

nutrients [9]. In general, restoration projects have been implemented in areas where exotic grass species and other competing species predominate [10], and the competition between grasses and tree species can affect the success of restoration, mainly during in the early stages of planting in which the seedlings are highly susceptible to many biotic and abiotic factors. Therefore, weed competition represents not only ecological and economic damage, but is also considered the main ecological filter for the establishment of native species [11], interfering with the availability of light, space, nutrients and water. Consequently, the scarcity of resources can cause physiological and morphological changes in seedlings, affecting the survival and initial development of planted species [12], which can lead to planting failure [10].

In this context, several methods to control competing plants have been used in restoration plantings, such as manual crowning by hoe, brush cutters or the use of herbicides, with manual crowning being the most used method [10,13,14]. However, depending on the technique, a large part of the project's resources may be compromised. It is worth mentioning that, in areas dominated by grasses of the genus *Urochloa* spp. and *Panicum* spp., weed competition control can represent up to 60% of the total cost of a restoration project [15]. Therefore, testing management techniques capable of overcoming the weed competition filter and reducing project costs is a major restoration challenge [16].

Currently, other techniques to control weed competition have been tested, such as the use of coverage with materials of synthetic and plant origin [10]; in addition to innovative technologies, such as *Nucleário* [14,17]. Regardless of raw material, these techniques are known as mulching, in which a coverage is added to the soil surface around seedlings [18,19], with the aim of acting as a physical barrier by preventing light from reaching the soil surface. Thus, mulching hinders germination and the development of seedlings of competing species, in addition to acting to control erosion processes and soil microclimatic characteristics, such as moisture and temperature [10,20,21]. When using organic materials, it also has the function of soil aggregation and nutrient supply [21].

Studies have shown the effectiveness of this technique in controlling weed competition [22,23] and have also indicated that mulching can influence the survival, growth and development of tree species [17,24–26] and even reduce the management costs of these species [25]. Thus, by associating these potentialities with the high cost of conventional techniques, such as manual crowning [15], the use of mulching as a crowning technique can be an efficient alternative in the control of exotic grasses, the development of native species and the reduction in management costs.

In this sense, the aim of this study was to test the effect of different weed competition control techniques on the performance of tree seedlings, and to answer the following questions: (i) Do crowning techniques alter soil microclimatic variables? (ii) Does the survival of tree seedlings differ among species and crowning techniques? (iii) Do crowning techniques promote seedling growth? (iv) Does the height and diameter increase vary among species?

2. Materials and Methods

2.1. Study Area

This study was conducted at the Jatobá Campus of the Federal University of Jataí (UFJ), state of Goiás, Brazil (17°55'53.76" S and 51°42'50.4" W), at approximate altitude of 655 m above sea level. The experimental area is 3200 m², being surrounded by forest fragments [27], and was once used to produce vegetables. It was later abandoned and currently has dense infestation of the invasive exotic grass *Urochloa decumbens* (Stapf R.D. Webster).

The climate of the region according to the Köppen classification is Aw, a tropical savannah with rain in summer and drought in winter [28]. Local precipitation rates range from 1200 to 2000 mm, with annual average of 1600 mm, with 90% of rainfall occurring from October to April [29]. Figure 1 shows the monthly averages of maximum and minimum temperatures and total monthly precipitation values, obtained throughout the experiment,

which took place in 2019. The experimental area was hit by a frost event that occurred on 18 July 2019.

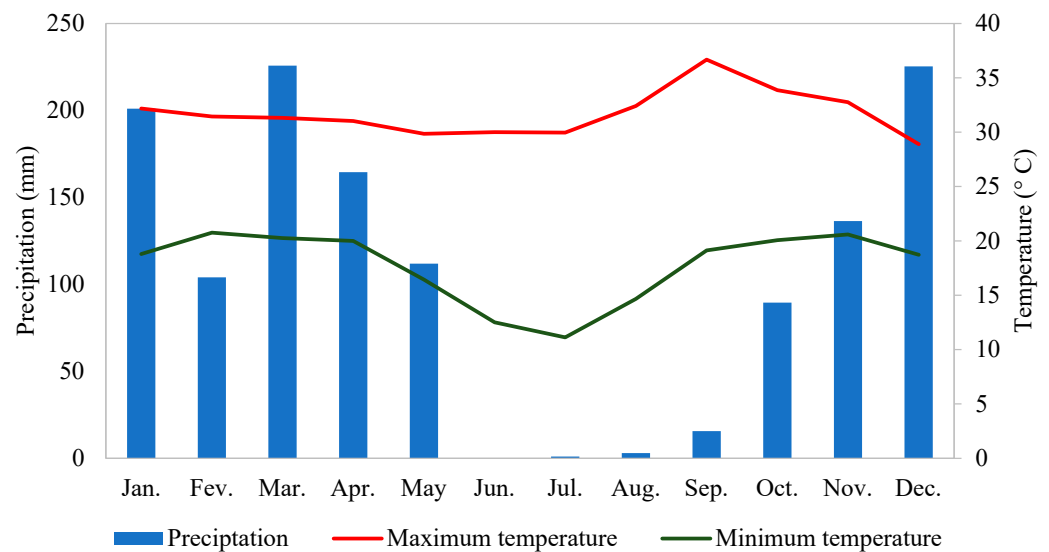


Figure 1. Monthly precipitation (mm) and minimum and maximum temperatures (°C), in 2019, at Federal University of Jataí, Goiás state, Brazil.

Dystrophic Red Latosol (Oxisol) predominates in the area, with clayey to very clayey texture, possibly originating from the basalt of the Serra Geral formation. These soils are deep, very porous and permeable, with low susceptibility to erosion [30].

2.2. Experimental Design

In March 2019, the experiment was implemented in a completely randomized design, with two study factors: crowning techniques (four) and tree species (six), resulting in 24 possible combinations, with 25 replicates of each. The following crowning techniques were used: (1) manual weeding by hoe; (2) cardboard; (3) wood chipping and (4) control. Details of the treatments are presented in Table 1. Six tree species common in the region were selected, which occur in forest formations of the Cerrado and with high potential for obtaining non-timber forest products, namely: jenipapo (*Genipa americana* L.), ingá-cipó (*Inga edulis* Mart.), paineira (*Ceiba speciosa* (A. St.-Hil.) Ravenna), cajazinho-do-cerrado (*Spondias mombin* L.), baru (*Dipteryx alata* Vogel) and angico (*Anadenanthera peregrina* var. *falcata* (Benth.) Altschul). One hundred seedlings of each species were planted, totaling 600 seedlings.

Table 1. Characteristics of the different treatments used in the study.

Treatment	Characteristics
Wood chipping	An amount of 7 L of freshly felled eucalyptus (<i>Eucalyptus urograndis</i>) wood chipping (measuring 3 to 5 cm) was used, since in a previous evaluation, this volume was sufficient to cover the entire soil surface with height of 3 cm in the dimension of 50 × 50 cm (Figure 2a).
Cardboard	Single-wall sheets were used, in which 50 × 50 cm plates were cut and placed on the soil, “fitting” the seedling in the center through a previously made cut (Figure 2b) [22]. To prevent its displacement by the wind action, it was fixed to the soil with the help of two bamboo sticks. To prevent termite attacks, both wood chipping and cardboard were previously immersed in CuSO ₄ solution.
Control	Without crowning of the spontaneous plants around the seedlings (Figure 2c).
Manual weeding (weeding)	Seedlings were crowned in the previously established delimitation (50 × 50 cm) using a hoe, repeating the action whenever spontaneous plants began to cover the height of the implanted tree species (Figure 2d).



Figure 2. Crowning techniques installed: (a) *Eucalyptus* chips; (b) cardboard; (c) demarcation of the area for manual weeding; (d) manual weeding.

Before planting, the experimental area was prepared by mowing (mechanically), harrowing and leveling. The spacing was 3 m between rows and 2 m between seedlings. Subsequently, pits were dug using a motor digger with an attached drill, with dimensions of 20 cm in diameter \times 40 cm in depth. Crowning techniques were applied 45 days after planting, and treatments were randomized by drawing for the crowning technique for each seedling. Before and after the planting of seedlings, inside and around the experimental area, leaf-cutting ants were controlled using granulated ant bait.

All seedlings were tagged and numbered in ascending order with an individual code from 1 to 600. The replanting of dead seedlings or those with some apparent damage was carried out over 30 days.

2.3. Data Collection

Thirty days after planting, the period for seedling hardening, prior to the installation of treatments, the height and diameter of individuals were measured (Table 2). The species had average height ranging from 18.21 cm (*G. americana*) to 61.75 cm (*S. mombin*), and average diameter from 3.96 mm (*A. peregrina* and *I. edulis*) to 9.51 mm (*C. speciosa*) (Table 2).

Table 2. Tree species, common name, average height (\pm standard error) and average diameter (\pm standard error), after 30 days of planting.

Species	Common Name	Height \pm SE (cm)	Diameter \pm SE (mm)
<i>Anadenanthera peregrina</i>	angico	46.58 \pm 1.41	3.96 \pm 0.10
<i>Ceiba speciosa</i>	paineira	52.59 \pm 1.27	9.51 \pm 0.23
<i>Dipteryx alata</i>	baru	21.09 \pm 0.44	4.49 \pm 0.09
<i>Genipa americana</i>	jenipapo	18.21 \pm 0.39	6.06 \pm 0.10
<i>Inda edulis</i>	ingá-cipó	28.02 \pm 0.68	3.96 \pm 0.09
<i>Spondias mombin</i>	cajazinho	61.75 \pm 1.42	5.52 \pm 0.11

To determine soil moisture and temperature (0–15 cm layer), 15 collections per treatment were performed. This evaluation was performed after the occurrence of the last precipitation event before the beginning of the dry season, in May 2019. Collections were performed at five times: 11, 22, 33, 44 and 60 days after precipitation, which included the months of June and July (Figure 1) and at 01:00 p.m. To determine moisture a HIDRO-Farm electronic moisture meter was used, and for soil temperature a digital skewer-type thermometer was used.

The number of surviving individuals of each species was counted weekly during the first 96 days after techniques were implemented. Subsequently, the evaluation was performed every two weeks until 219 days. The survival percentage (S%) was calculated by the ratio between the number of individuals planted and the number of dead ones for each species and treatment.

All seedlings were individually evaluated, and signs of anomalies were described based on a predetermined pattern with the aim of identifying the causes of mortality, which were: (i) seedling quality: no leaves and/or dead apical buds; (ii) drought: yellowing and gradual loss of leaves; wilted leaves; (iii) herbivory: greater than 50% of leaves; (iv) others: diseases and/or unidentified causes.

Plant growth was monitored by measuring height using a tape measure from the base of the plant to the apex of the highest leaf, and stem diameter was determined (5 cm above the root collar) using a digital caliper. After crowning techniques were implemented, seedlings were assessed for height and diameter at three different times: 5 days (20 April), 96 days (20 July) and 219 days (20 November).

Seedlings with more than one stem had their unit diameters transformed into equivalent diameter (dg) [31]. The equivalent diameter is a single diameter value obtained from the area of multiple branches, and is estimated using Equation (1):

$$dg = \frac{\sqrt{4}}{\pi} \times g \quad (1)$$

where dg represents equivalent diameter (mm) and g represents area of the individual branch.

To calculate the height and equivalent diameter increments, the measurements obtained in the growth assessments at 5, 96 and 219 days were used, determining three increments: 5 to 96 days (91-day period), 96 to 219 days (123-day period) and 5 to 219 days (214-day period).

2.4. Statistical Analysis

The soil temperature and moisture values were compared among crowning techniques using analysis of variance ($p \leq 5\%$) [32] and Tukey's test ($p \leq 5\%$) [33]. The survival rate among crowning techniques and among species 219 days after the experiment was installed was analyzed using generalized linear models (GLMs) with binomial distribution [34], applying the chi-square test ($p \leq 5\%$) [35] and, subsequently, the Tukey test ($p \leq 5\%$). The height and diameter increase values, among crowning techniques and species, were compared using analysis of variance ($p \leq 5\%$) and Tukey's test ($p \leq 5\%$). In the height increase models, height data before the installation of techniques were used as a covariate; and in diameter increase models, the diameter values of the first measurement before the installation of techniques were used as a covariate. The assumptions of the analysis of variance for each model were checked by visualizing the distribution of residuals. The outliers of each model were removed from the analysis. All statistical procedures were performed using R 4.3.0 Statistical Software® [36].

3. Results

3.1. Soil Moisture and Temperature

Crowning techniques significantly influenced the soil microclimate ($p \leq 0.05$). In the first three evaluations, moisture content was higher in the cardboard (19.36%) and wood chipping (23.93%) techniques, and lower in the control (16.59%) and weeding (19.70%) techniques (Figure 3A).

After 44 days, wood chipping maintained the highest moisture content, followed by cardboard with intermediate value, while the other techniques presented lower values. In the last evaluation, cardboard and control had the highest and lowest moisture content, respectively (Figure 3A).

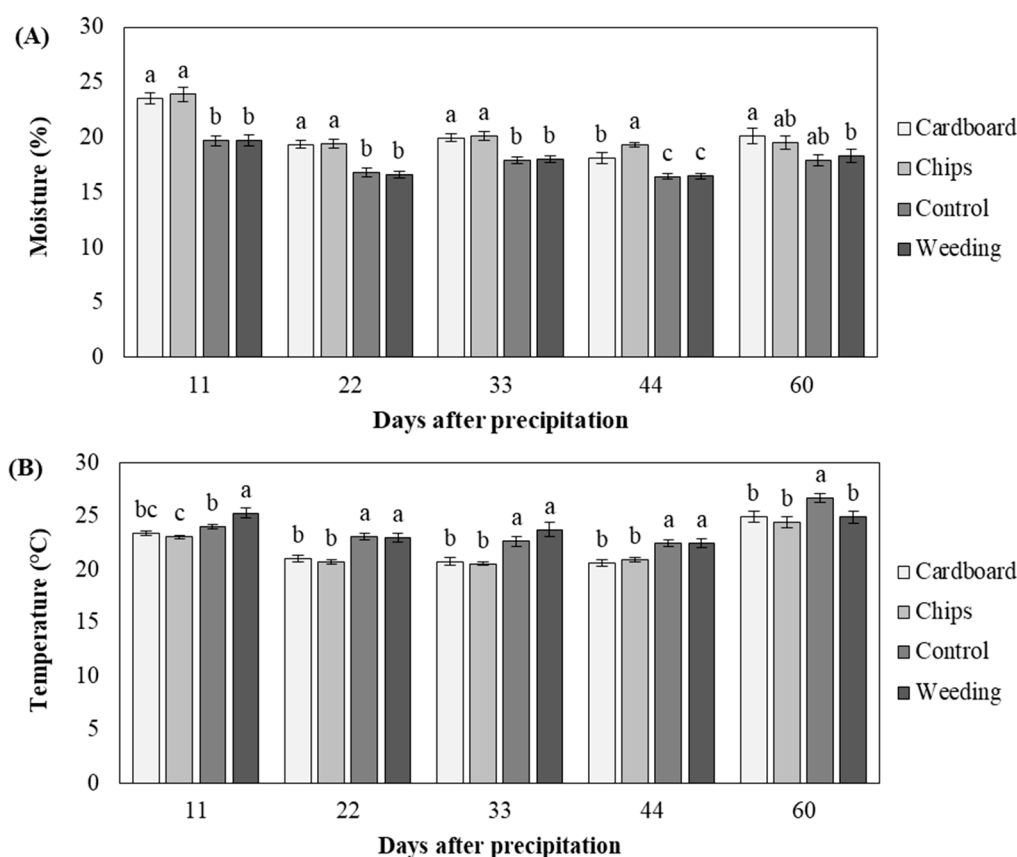


Figure 3. Moisture (%) (A) and temperature (°C) (B) of soil on different measurement days (11, 22, 33, 44 and 60), by crowning technique. Bars indicate mean values \pm standard error. Bars with the same letters, for each time, did not differ by Tukey's test at 5% significance.

Temperature also differed among crowning techniques ($p \leq 0.05$) (Figure 3B). At 11 days, the highest temperature was observed in the weeding treatment (25.2 °C) and the lowest in wood chipping (23.0 °C), while for control and cardboard, intermediate values of 23.9 °C and 23.4 °C, respectively, were observed (Figure 3B). In the three subsequent evaluations, the highest averages were observed for control and weeding, and the lowest for cardboard and wood chipping treatments. In the last evaluation, the control treatment presented the highest temperature (26.7 °C), while the other treatments presented values close to 25 °C (Figure 3B).

3.2. Seedling Survival

In the first 30 days after seedling planting, 99 dead individuals were counted, with 83.5% survival rate. The uprooting of seedlings by animals caused the death of 52 individuals and occurred in a concentrated manner in planting lines close to a gallery forest. Seedlings killed by diseases, pests, poor quality or other unclear reasons totaled 47 individuals.

After the installation of treatments (45 days) and until the end of the experiment, 53 dead individuals were counted, with 91% survival rate. The species differed in survival rate ($\chi^2 = 76.6$; $p < 0.001$), ranging from 71% (*I. edulis*) to 100% (*D. alata*) (Figure 4A). The other species presented values between 85% and 96%.

The causes of mortality were associated with frost (18 deaths), seedling quality (14), lack of water (12), predation (four) and other factors (seven). In relation to frost, 117 individuals were affected and showed signs of injury, 59 of *I. edulis*, 34 of *G. americana*, 11 of *S. mombin* and *C. speciosa* and two of *D. alata* individuals. Individual evaluation allowed associating 17 deaths of *I. edulis* individuals and one of *G. americana* to frost. The other affected seedlings were recovered.

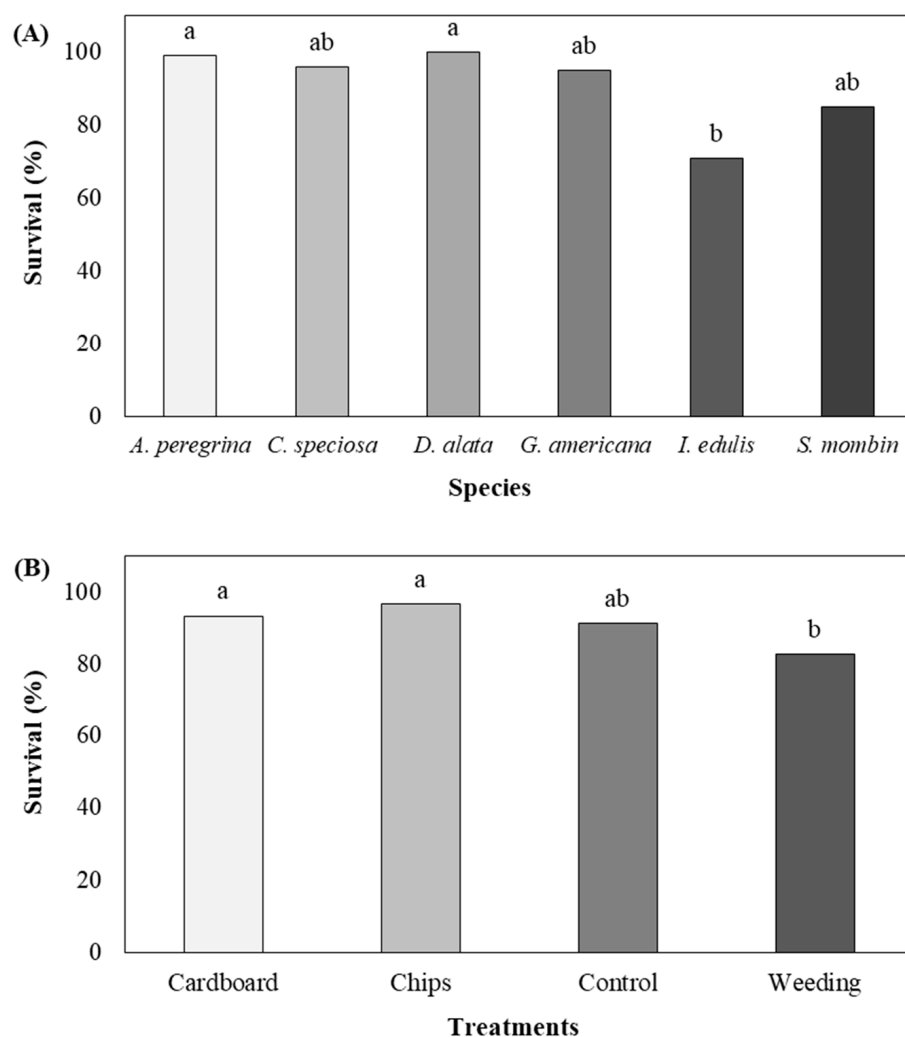


Figure 4. Percentage of survival (%) among tree species (A) and crowning techniques (B), 219 days after the installation of crowning techniques. Bars with the same letters, for each time, did not differ by Tukey's test at 5% significance.

The crowning techniques affected the survival rate ($\chi^2 = 21.9$; $p < 0.001$) (Figure 4B), with higher values for wood chipping (96.7%) and cardboard (93.3%) techniques, and lower for weeding (83.7%). Control (91.3%) showed intermediate survival rate and did not differ from the other techniques (Figure 4B).

3.3. Seedling Growth

The species under study showed differences in height increase in the three intervals: 5 to 96 days ($F = 20.81$; $p < 0.001$), 96 to 219 days ($F = 134.76$; $p < 0.001$) and 5 to 219 days ($F = 139.70$; $p < 0.001$) (Figure 5A). However, no significant effects of crowning techniques on height increase were found ($p > 0.05$) (Figure 5B).

Height increase in the interval between 5 and 96 days was higher for species *I. edulis* and *A. peregrina*, and lower for *D. alata* and *S. mombin*, whereas *G. americana* and *C. speciosa* did not differ from the other species, except for *S. mombin*, which showed lower and negative growth (Figure 5A). In the intervals from 96 to 219 days and 5 to 219 days, *A. peregrina* showed the highest height increase and *S. mombin* maintained lower and negative increase. The other species showed intermediate increases (Figure 5A).

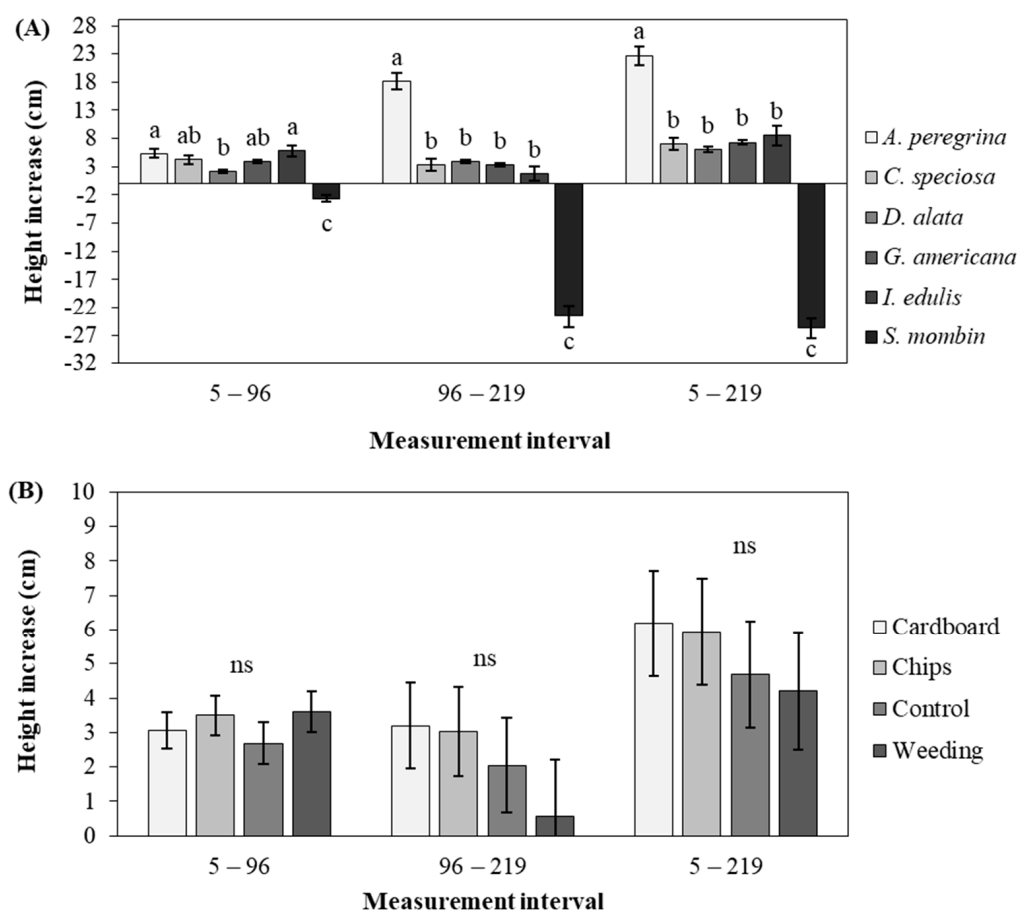


Figure 5. Height increase (cm) among tree species (A) and crowning techniques (B), in three intervals (5 to 96, 96 to 219 and 5 to 219 days). Bars indicate mean values \pm standard error. Values with the same letters, for each interval, did not differ by Tukey's test at 5% significance. ns: not significant.

Diameter increase differed among species in the three periods ($p < 0.001$) (Figure 6A). In the first interval, between 5 and 96 days ($F = 28.36$), *C. speciosa* showed the highest value, while *A. peregrina*, *D. alata* and *S. mombin* had the lowest values. *I. edulis* and *G. americana* presented intermediate values (Figure 6A).

For the interval between 96 and 219 days ($F = 19.29$), during the dry period, in general, species presented the lowest increase in height. In this interval, *A. peregrina* obtained the highest increase, while *S. mombin* had lower and negative increase (Figure 6A). The other species presented intermediate values. The diameter increases between the last (219 days) and the first evaluation (5 days) also differed among species ($F = 39.41$), in which *C. speciosa* presented the highest value, followed by *G. americana*, *I. edulis* and *A. peregrina*. *D. alata* presented an intermediate value and *S. mombin* the lowest value (Figure 6A).

The diameter increase did not differ among crowning techniques in the periods between 5 and 96 days ($F = 1.26$; $p = 0.28$) and 96 to 219 days ($F = 1.25$; $p = 0.30$) (Figure 6B). However, in the interval from 5 to 219 days, differences were observed ($F = 4.69$; $p = 0.003$), in which seedlings in the wood chipping treatment presented a higher mean value compared to control and weeding techniques. Seedlings in the cardboard treatment presented intermediate values and did not differ from the other techniques (Figure 6B).

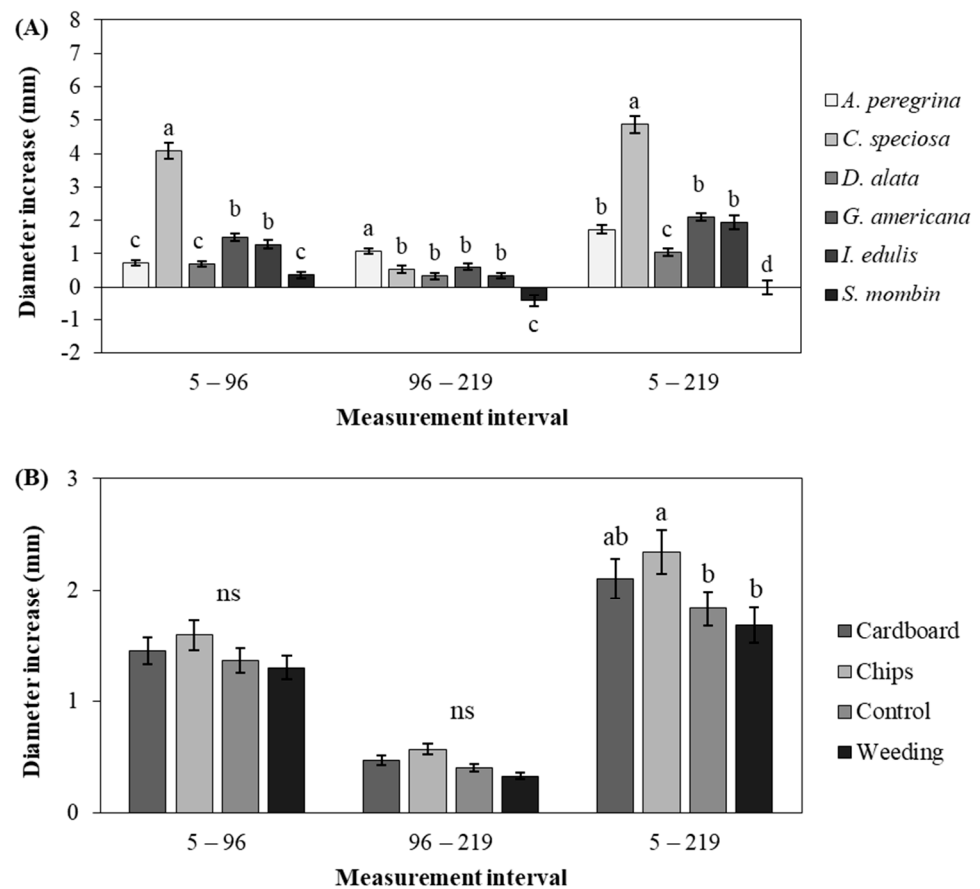


Figure 6. Diameter increase (cm) among tree species (A) and crowning techniques (B), in three intervals (5 to 96, 96 to 219 and 5 to 219 days). Bars indicate mean values \pm standard error. Values with the same letters, for each interval, did not differ by Tukey's test at 5% significance. ns: not significant.

4. Discussion

4.1. Organic Mulching Changes Soil Microclimate

The results of this study showed that cardboard and *Eucalyptus urograndis* chipping mulches increased and maintained soil moisture and decreased soil temperature for a longer period, mainly in the months of water deficit (May and June). This occurred because these materials prevent the direct action of sunlight and wind on the soil surface, keeping it moist, while weeding, for example, exposes the soil to the direct action of sun and wind, resulting in greater desiccation [19]. Other studies, evaluating soil moisture under cardboard [25] and comparing environmental variables between mulching techniques [19], also found positive effects of organic mulching on soil moisture. The temperature below cardboard can be up to 8 °C lower than that of crowned areas exposed to the sun, contributing to the maintenance of soil moisture [25], and it was found that in rainfall less than 5 mm, cardboard reduced soil moisture when compared to weeding [25]. Mulch derived from dead plant material was efficient in protecting the soil surface layer against the action of the wind, maintaining moisture (10% more moisture), resulting in a slower drying process (8.5 °C lower) [25]. Thus, the use of mulching as crowning techniques reduces the soil desiccation speed, maintaining moisture, compared to techniques that remove all plant biomass around seedlings, such as manual control by hoe [17,19,25].

4.2. Seedling Survival

Overall, a high seedling survival of 91% was observed in this study. In Cerrado areas, studies have indicated that the seedling survival rate in the initial phase is considered high with values above 81%, median from 80 to 61%, and low with values below 61% [37]. For

the species under study, *Inga edulis* had lower survival rates (71%) compared to the other species, which presented values above 85%, with *A. peregrina* and *D. alata* standing out with 100% survival rate. Some studies corroborate the findings of this study, such as 90% for *D. alata* (nucleário: 97.5%; cardboard: 94.8%; weeding: 90.1) [17], 77% for *I. edulis* [25], and 100% for *S. mombin*, [38].

The main causes of seedling mortality were associated with climate extremes, temperature and moisture, i.e., frost and drought. Both factors have been recognized as the main limiting factors for vegetation establishment and development [39] and low temperatures, particularly when they occur in tropical regions, are associated with high seedling mortality [40]. Although *I. edulis* can withstand low temperatures and cold winds, its seedlings are sensitive to frost [41], which may explain the high number of affected individuals and, consequently, the higher mortality rate. High mortality rate was found for *Inga vera* and *Cupania vernalis* after frost, species that also showed the highest damage degree [40]. The authors explain that pioneer species are more sensitive to frost, which may compromise their survival, which corroborated findings of this study.

Organic mulching made of wood chipping and cardboard, by conserving moisture and reducing soil temperature, may have contributed, in general, to the survival rate of species under study, which exceeded 93% for cardboard and 96% for wood chipping. These results are consistent with Gonçalves's study [25], which found a high survival rate one year after the experiment installation for crowning made with cardboard (80.7% survival rate), and with Silva's research [22] which found that treatments crowned with *Eucalyptus* spp. chipping obtained a greater survival rate with values that reached approximately 82%. Both authors associated survival with the better microclimatic quality under wood chipping, and concluded that these better conditions, linked to microbiological development, contributed to the positive results.

It is relevant to mention that, before the installation of crowning techniques, an important mortality event happened, it was associated with predation and occurred in a concentrated manner in part of the experimental area and may have been caused by herbivores, which are common in the region. Herbivory and/or predation in forest plantations have direct influence on the formation and structuring of plant communities, this process being a biotic filter, and may occur selectively [42,43]. Studies have indicated that young seedlings are more susceptible to predation, being more attractive to small and medium-sized mammals, or other potential predators, due to the greater palatability of their leaves [44]. Another factor that may increase seedling predation is the proximity of forest formations associated with watercourses [45], which may shelter different animal species, a fact observed in this experiment. Thus, natural predatory processes that occur in young plantations can compromise the restoration success [42], and therefore measures to prevent predation are necessary, such as fencing the area.

4.3. Height and Diameter Growth

The crowning techniques did not affect the height increase of species, but differences were observed among species. Some studies have reported that the height growth of tree species is a variable that has commonly not responded to crowning techniques [17,25,46], even when these increased soil water availability [17,25]. However, some recent studies testing the effects of mulching from carnaúba (*Copernicia prunifera*), a native palm typical of the Caatinga Biome, in Brazil, on the establishment of shrub and tree species showed positive effects of this material on total average height of 15 species [47] and on the height growth rate of the species *Anadenanthera colubrina*, *Hymenaea courbaril* and *Senna spectabilis*, indicating the potential mulching use for these species [48].

The species under study maintained a pattern of height increase throughout the study period, with emphasis on *A. peregrina*, which grew on average 22 cm in the evaluated period. The other species grew between 6 and 8.5 cm, except for *S. mombin*, which obtained negative increase. *A. peregrina* has shown good growth in plantations in the Atlantic Forest [49] and Cerrado [50] regions, showing to be a good option in restoration plantations. On the

other hand, although *S. mombin* is indicated for the recovery of degraded areas [51], the individuals analyzed obtained lower and negative increase. However, this result may be associated with the shorter hardening period of seedlings in the nursery, which is a preponderant factor for the survival and development of seedlings in the field [52]. In fact, *S. mombin* seedlings presented etiolation when they arrived in the field, and it was necessary to use support with bamboo stakes to keep seedlings firm. In addition, the dry period may have contributed to the reduction in height growth for this species, in which *S. mombin* seedlings showed signs probably caused by water deficit, such as gradual loss of leaves, drying of branches and death of apical buds, which possibly contributed to the negative increase.

The crowning techniques influenced the diameter increase of species, which also differed from each other. The growth of *C. speciosa*, with diameter increase twice as high as the other species, has also been used in restoration plantations [53] and in this study, it may be related to the maintenance of soil moisture provided by organic mulching, given that the species has high water efficiency [54].

Gains in diameter increase especially provided by wood chipping may be associated with the better microclimatic conditions also verified for this technique. Thus, while wood chipping allows water infiltration into the soil, it prevents the direct action of sunlight and wind on the soil surface [19]. Therefore, this specific technique increases and maintains soil moisture for a longer period, contributing to the diameter growth of seedlings [46]. Previous studies have shown no differences in diameter growth among seedling crowning techniques [17,25,46]. However, this study indicated that crowning with *Eucalyptus urograndis* chipping can, as previously described, increase the survival rate and diameter growth of tree species seedlings and, consequently, the establishment of these species. Seedlings with larger stem diameter tend to adapt better to the environment, due to their greater root formation capacity, explaining their better performance [55]. Thus, the effects of the wood chipping technique on the diameter increase of tree species demonstrate the potential of this material as an alternative crowning technique in restoration plantations. Furthermore, it avoids weed competition in field conditions and improves soil microclimate characteristics [46].

5. Conclusions

Our study demonstrated that crowning techniques with cardboard and wood chipping have a significant impact on soil conditions and seedling performance. Both methods were effective in increasing soil moisture, reducing soil temperature and increasing seedling survival, whereas manual weeding negatively affected these parameters. Among the techniques evaluated, the use of wood chipping not only contributed to seedling survival but also promoted increases of diameter. In this context, this technique's effectiveness highlights its potential as a practice in restoration plantings, especially in tropical regions facing water deficits or extreme temperature conditions. Given the importance of restoration initiatives in combating environmental degradation and mitigating the negative impacts of climate change, the use of wood chipping in restoration plantings could be an effective strategy to enhance seedling establishment, thereby contributing to more resilient and sustainable restoration outcomes.

Author Contributions: Conceptualization, D.L.M. and M.N.D.; methodology, D.L.M. and M.N.D.; validation, D.L.M., M.N.D., L.M.d.S. and E.M.d.S.; formal analysis, D.L.M. and D.S.P.; investigation, D.L.M., M.N.D., M.S.d.F., L.M.d.S., E.M.d.S., D.S.P., C.R.A., W.C.F. and F.A.G.G.; writing—original draft preparation, M.N.D.; writing—review and editing, D.L.M., M.S.d.F., D.S.P., C.R.A., W.C.F. and F.A.G.G.; supervision, D.L.M. and F.A.G.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available in this article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Instituto Nacional de Pesquisas Espaciais (INPE). Nota Técnica PRODES Cerrado 2021. Governo do Brasil—Ministério da Ciência, Tecnologia e Inovações, 2021. Available online: <https://www.gov.br/inpe/pt-br/assuntos/ultimas-noticias/nota-tecnica-prodes-cerrado-2021> (accessed on 20 January 2022).
2. Ribeiro, J.F.; Walter, B.M.T. Fitofisionomias do bioma cerrado. In *Cerrado: Ambiente e Flora*; Sano, S.M., Almeida, S.P., Eds.; EMBRAPA-CPAC: Planaltina, Brazil, 2008; pp. 89–166.
3. Bustamante, M. Política de Clima Negligencia o Cerrado—Mais Uma Vez Plano Entregue à ONU não Menciona o Segundo Maior Bioma do País. Available online: <https://envolverde.com.br/politica-de-clima-negligencia-o-cerrado/> (accessed on 16 March 2023).
4. Bolson, S.H. O Cerrado nas Metas Brasileiras do Acordo de Paris: A Omissão do Estado Brasileiro com o Desmatamento na Cumeeira da América do Sul. *Rev. Direito Ambient. Socioambientalismo* **2018**, *4*, 112–131. [[CrossRef](#)]
5. Myers, N.; Mittermeier, R.A.; Mittermeier, C.G.; da Fonseca, G.A.B.; Kent, J. Biodiversity hotspots for conservation priorities. *Nature* **2000**, *403*, 853–858. [[CrossRef](#)] [[PubMed](#)]
6. Barbosa, A.S. *Cerrado. o Laboratório Antropológico Ameaçado Pela Desterritorialização*; Cadernos IHU Ideias, Instituto Humanitas, Universidade do Vale do Rio dos Sinos: São Leopoldo, Brazil, 2017; Volume 15.
7. Durigan, G. Reflexões sobre a restauração ecológica em regiões de cerrado. In *Simpósio de Restauração Ecológica*; Imprensa Oficial do Estado de São Paulo: São Paulo, Brazil, 2013; pp. 33–37.
8. Carpanezzi, O.T.B. Espécies Vegetais Tóxicas No Parque Estadual de Vila Velha: Subsídios Para Controle e Erradicação. Monograph (Specialization in Environmental Analysis). Ph.D. Thesis, Universidade Federal do Paraná, Curitiba, Brazil, 2007.
9. Haling, R.E.; Campbell, C.D.; Tighe, M.K.; Guppy, C.N. Effect of competition from a C4 grass on the phosphorus response of a subtropical legume. *Crop Pasture Sci.* **2013**, *64*, 985–992. [[CrossRef](#)]
10. de Resende, A.S.; Leles, P.S.S. (Eds.) *Controle de Plantas Daninhas em Restauração Florestal*, 1st ed.; Embrapa: Brasília, Brazil, 2017.
11. Holl, K.D.; Loik, M.E.; Lin, E.H.V.; Samuels, I.A. Tropical montane forest restoration in Costa Rica: Overcoming barriers to dispersal and establishment. *Restor Eco* **2001**, *8*, 339–349. [[CrossRef](#)]
12. Pitelli, R.A.; Marchi, S.R. Interferência das plantas daninhas nas áreas de reflorestamento. In *Seminário Técnico Sobre Plantas Daninhas E O Uso de Herbicidas em Reflorestamento*; SIF: Belo Horizonte, Brazil; Anais, France, 1991; pp. 1–11.
13. Santos, F.A.M.D.; Leles, P.S.D.S.; da Silva Resende, A.; Nascimento, D.F.D.; Santos, G.R.D. Estratégias de controle de braquiárias *Urochloa* spp. na formação de povoamento para restauração florestal. *Ciência Florest.* **2020**, *30*, 29–42. [[CrossRef](#)]
14. Martins, S.V.; de Paula Braz, J.; Villa, P.M.; Alves WV, L.; Valente, M.L.; Kruschewsky, G.C.; Dias, A.A.; Nabeta, F.H. Avaliação de núcleiros como técnica de restauração florestal em Mariana, MG, Brasil. *Pesqui. Florest. Bras.* **2022**, *42*, e202002154. [[CrossRef](#)]
15. Leles, P.S.S.; Oliveira Neto, S.N.; Alonso, J.M. Restauração florestal em diferentes espaçamentos. In *Recomposição Florestal da Bacia do Rio Guandu*; Leles, P.S.S., Oliveira Neto, S.N., Eds.; Editora Rural: Sao Paulo, Brazil, 2015; pp. 101–153.
16. Durigan, G.; Melo, A.C.G. An overview of public policies and research on ecological restoration in the state of São Paulo, Brazil. In *Biodiversity Conservation in the America: Lessons and Policy Recommendations*, 1st ed.; Figueroa, E., Ed.; Editorial FEN—Universidad de Chile: Santiago, Chile, 2011; pp. 325–355.
17. Benites, R.M.A.; Guerra, A.; Reis, L.K.; Ferreira, B.H.S.; Borges, F.L.G.; Ferreira, I.J.K.; Abrahão, M.; Garcia, L.C. Núcleo, cardboard, or manual crowing: Which maintenance technique is most cost-effective in tree seedling survival establishment? *J. Environ. Manag.* **2020**, *270*, 110900. [[CrossRef](#)] [[PubMed](#)]
18. Likatas, A.; Clark, J.A.; Monteith, J.L. Measurements of the heat balance under plastic mulches. *Agric. For. Meteorol.* **1986**, *36*, 227–239. [[CrossRef](#)]
19. Streck, N.A.; Schneider, F.M.; Buriol, G.A. Modificações físicas causadas pelo mulching. *Rev. Bras. Agrometeorol.* **1994**, *2*, 131–142.
20. Palhares, A.O. Contribuição Para Recuperação de Matas Ciliares: O Uso de Papelão em Substituição a Capina de Coroamento, No Plantio e Condução de Mudanças Florestais. Master's Thesis, Instituto de Pesquisas Tecnológicas do Estado de São Paulo, São Paulo, Brazil, 2011.
21. Kader, M.A.; Senge, M.; Mojid, M.A.; Ito, K. Recent advances in mulching materials and methods for modifying soil environment. *Soil Tillage Res.* **2017**, *168*, 155–166. [[CrossRef](#)]
22. Silva, F.F.; Resende, A.S.; Santos, T.A.; Chaer, G.M. Use of Cardboard Disks for Crowning Seedlings in Reforestation. *Floresta Ambiente* **2018**, *25*, e20160261. [[CrossRef](#)]
23. Gonçalves, F.L.A.; Aximoff, I.; Resende, A.S.; Chaer, G.M. Efficiency of cardboard crowning on the suppression of invasive alien grasses. *Floresta Ambiente* **2021**, *23*, e20210021. [[CrossRef](#)]
24. González-Tokamn, D.M.; Barradas, V.L.; Boege, K.; Domínguez, C.A.; Del-Val, E.; Saucedo, E.; Martínez-Garza, C. Performance of 11 tree species under different management treatments in restoration plantings in a tropical dry forest. *Restor Eco* **2018**, *26*, 642–649. [[CrossRef](#)]
25. Gonçalves, F.L.A.; Resende, A.S.; Lima, I.S.S.; Chaer, G.M. Manual crowning versus cardboard in forest restoration: Costs and effect on seedling development. *Planta Daninha* **2018**, *36*, e018167569. [[CrossRef](#)]
26. Dias, M.M.M.; Santana, J.E.S.; Leles, P.S.S.; de Resende, A.S.; Ribeiro, J.G. Coroamento com papelão para controle de braquiária na formação de povoamento para restauração florestal. *Pesq. Flor. Bras.* **2019**, *39*, e201801713. [[CrossRef](#)]
27. Oliveira, L.C.S.; Guimarães, J.C.O.; Souza, I.C.S.; Lima, C.M.; Ferreira, W.C. Levantamento florístico e fitossociológico da regeneração natural de uma mata de galeria localizada no município de Jataí—GO. *Glob. Sci. Technol.* **2015**, *8*, 59–77. [[CrossRef](#)]

28. Alvares, C.A.; Stape, J.L.; Sentelhas, P.C.; Gonçalves, J.D.M.; Sparovek, G. Köppen's climate classification map for Brazil. *Meteorol. Z.* **2013**, *22*, 711–728. [[CrossRef](#)]
29. Assunção, H.F.; Scopel, I. Relações radiométricas em Jataí—GO. In *II Congresso Brasileiro de Biometeorologia*; Sbiomet: Goiânia, Brazil, 1998; pp. 251–256.
30. Scopel, I.; Silva, M.R. Erodibilidade no estado de Goiás. *Uniciência* **2001**, *8*, 123–132.
31. Loëtsch, F.; Haller, K.E.; Zöhrer, F. *Forest Inventory*, 2nd ed.; BLV Verlagsgesellschaft: Munich, Germany, 1973; Volume 2, 469p.
32. Fisher, R.A. *Statistical Methods and Scientific Inference*, 2nd ed.; Hafner Publishing Co.: New York, NY, USA, 1959.
33. Odeh, R.E.; Evans, J.O. Algorithm AS 70: Percentage Points of the Normal Distribution. *Appl. Stat.* **1974**, *23*, 96–97. [[CrossRef](#)]
34. McCullagh, P.; Nelder, J.A. *Generalized Linear Models*; Chapman and Hall: London, UK, 1989.
35. Hope, A.C.A. A simplified Monte Carlo significance test procedure. *J. R. Stat. Soc. Ser. B* **1968**, *30*, 582–598. [[CrossRef](#)]
36. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2021.
37. Moreira, C.D.D.; Sales, N.L.P.; Carvalho, L.C.; Saraiva, L.S.; Magalhães, L.P.P. Sobrevivência de espécies arbóreas em área degradada do cerrado no norte de Minas Gerais. In *IV Simpósio Nacional Sobre Restauração Florestal*; Reforest: Belo Horizonte, Brazil; Anais, France; Viçosa, Brazil, 2019; pp. 312–318.
38. Silva, K.J.S.; Cinque Mariano, D.; Okumura, R.S.; Vieira, A.L.M.; Ebling, Â.A. Effects of mineral and organic fertilization on the growth of *Spondias mombin* in an area of environmental recovery in the Amazon region. *Braz. J. Dev.* **2020**, *6*, 59960–59970. [[CrossRef](#)]
39. Charra-Vaskou, K.; Charrier, G.; Wortemann, R.; Beikircher, B.; Cochard, H.; Ameglio, T.; Mayr, S. Drought and frost resistance of trees: A comparison of four species at different sites and altitudes. *Ann. For. Sci.* **2012**, *69*, 325–333. [[CrossRef](#)]
40. Rorato, D.G.; Araujo, M.M.; Tabaldi, L.A.; Turchetto, F.; Griebeler, A.M.; Berghetti, Á.L.P.; Barbosa, F.M. Tolerance and resilience of forest species to frost in restoration planting in southern Brazil. *Restor Eco* **2017**, *25*, 1–6. [[CrossRef](#)]
41. Vertflora. Descrição do Ingá Cipó (*Inga edulis*). Available online: <https://vertflora.com.br/produto/inga-cipo> (accessed on 20 January 2022).
42. Massad, T.J.; Chamber, J.Q.; Rolim, S.G.; Jesus, R.M.; Dyer, L.A. Restoration of pasture to forest in Brazil's Mata Atlântica: The roles of herbivory, seedling defenses, and plot design in reforestation. *Restor Eco* **2011**, *19*, 257–267. [[CrossRef](#)]
43. Massad, T.J. Interactions in tropical reforestation—How plant defence and polycultures can reduce growth-limiting herbivory. *Appl. Veg. Sci.* **2012**, *15*, 338–348. [[CrossRef](#)]
44. Maran, J.C.; Rosot, M.A.D.; Radomski, M.I.; Kellermann, B. Análise de sobrevivência e germinação em plantios de *Araucaria angustifolia* derivados de mudas e sementes. *Ciência Florest.* **2016**, *26*, 1349–1360. [[CrossRef](#)]
45. Silva, B.I.A. Predação de Mudas de Castanheira em Área Sob Restauração Florestal na Amazônia. Master's Thesis, Universidade Federal Rural da Amazônia/Museu Paraense Emílio Goeldi, Belém, Brazil, 2019; p. 48.
46. Silva, L.C.R.; Corrêa, R.S. Sobrevivência e crescimento de seis espécies arbóreas submetidas a quatro tratamentos em área minerada no cerrado. *Rev. Árvore* **2008**, *32*, 731–740. [[CrossRef](#)]
47. Souza, M.P.; Chaer, G.M.; Gonçalves, F.L.A. Efeito da transposição de topsoil e mulching de *Copernicia prunifera* (Mill.) HE Moore na revegetação de área degradada na Caatinga. *Sci. For.* **2022**, *50*, e3923. [[CrossRef](#)]
48. Gonçalves, F.L.A.; Aximoff, I.; Resende, A.S.D.; Chaer, G.M. Effect of Carnaúba Bagana Mulching on Tree Species Planted in Degraded Areas in Caatinga. *Floresta Ambiente* **2023**, *30*, e20220091. [[CrossRef](#)]
49. de Lima, J.A.; de Santana, D.G.; Nappo, M.E. Comportamento inicial de espécies na revegetação da mata de galeria na fazenda Mandaguari, em Indianópolis, MG. *Rev. Árvore* **2009**, *33*, 685–694. [[CrossRef](#)]
50. Passaretti, R.A.; Pilon, N.A.L.; Durigan, G. Weed control, large seeds and deep roots: Drivers of success in direct seeding for savanna restoration. *Appl. Veg. Sci.* **2020**, *23*, 1–11. [[CrossRef](#)]
51. Amorim, I.A. Sobrevivência e Crescimento Inicial de Mudas de Cajazeira (*Spondias mombin* L.) em Recuperação de Ecossistema Ripário No Sudeste Paraense. Bachelor's Thesis, Universidade Federal do Sul e Sudeste do Pará, Curso de Agronomia, Marabá, Brazil, 2016.
52. Teixeira, L.A.F. Influência da Rustificação No Comportamento Fisiológico de Mudas de *Eucalyptus Urograndis* Submetidas ao Déficit Hídrico. Master's Thesis, Universidade Federal de Lavras, Lavras, Brazil, 2012.
53. Silva KD, A.; Martins, S.V.; Miranda, A.; Demolinari RD, A.; Lopes, A.T. Restauração florestal de uma mina de bauxita: Avaliação do desenvolvimento das espécies arbóreas plantadas. *Floresta Ambiente* **2016**, *23*, 309–319. [[CrossRef](#)]
54. Bueno, M.M.; dos Santos Leles, P.S.; Goncalves Abreu, J.F.; Dos Santos, J.J.S.; de Carvalho, D.F. Water requirement and growth indicators of forest tree species seedlings produced with automated irrigation management. *PLoS ONE* **2020**, *15*, e0238677. [[CrossRef](#)]
55. Scalon, S.P.Q.; Mussury, R.M.; Rigoni, M.R.; Veraldo, F. Crescimento inicial de mudas de espécies florestais nativas sob diferentes níveis de sombreamento. *Rev. Árvore* **2002**, *26*, 1–5.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.