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Performance of *Guazuma ulmifolia* Lam. in subtropical forest restoration

Desempenho de Guazuma ulmifolia *Lam. na restauração florestal subtropical*

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Abstract

We evaluated the initial development of *Guazuma ulmifolia* Lam. in a reforestation experiment in the southwestern region of Parana State, Southern Brazil. In a 70 native tree species plantation (3x2 m spacing) data were collected biannually, up to 48 months, from 72 individuals of *Guazuma ulmifolia*. The species performance was evaluated regarding its survival (96%), root collar diameter (6.79 cm), total height (12.84 m), crown projection area (14.36 m^2) and crown volume (49.86 m^3). The species growth at the age of 48 months, associated to its high survival and sprouting rates, tells of excellent behavior in the region, and it could be highly recommended as a shading species for fast canopy fulfillment in forest restoration projects, especially in regions with frost occurrence.

Keywords: Initial growth; Pioneer species; Ecological restoration.

Resumo

O objetivo deste estudo foi avaliar o desenvolvimento inicial de *Guazuma ulmifolia Lam*. em um plantio de restauração ecológica na região sudoeste do estado do Paraná, sul do Brasil. Em um plantio realizado com 70 espécies arbóreas nativas, sob espaçamento 3 x 2 m, coletaram-se dados semestrais, até os 48 meses, de 72 indivíduos da espécie *Guazuma ulmifolia*. O desempenho das plantas foi avaliado quanto à sobrevivência, diâmetro do colo, altura total, área de projeção de copa e volume de copa. A espécie apresentou excelente performance aos 4 anos de idade: sobrevivência (96%), diâmetro de colo (6,79 cm), altura total (12,84 m), área de projeção de copa (14,36 m^2) e volume de copa (49,86 m^3). O crescimento da espécie aos 48 meses de idade associada à sua alta taxa de sobrevivência e rebrota, confere excelente performance na região, podendo ser altamente recomendada para utilização como espécie sombreadora para rápido preenchimento de dossel em projetos de restauração florestal, especialmente em regiões com ocorrência de geadas.

Palavras-chave: Crescimento inicial; Espécies pioneiras; Restauração ecológica.

INTRODUCTION

In order to comprehend the forest restoration development, it is necessary to acquire knowledge about the survival and growth rates of the species used for this purpose. Pioneer

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species contribute with their fast development, capacity to generate shade and high biomass production (Rodrigues et al., 2009). Fauna attractiveness is another characteristic that must be considered to select species, as the restoration succession depends on the established community. Species that somehow attract dispersing animals should be preferred in forest restoration projects as well (Bechara et al., 2016; Reis et al., 2010).

Guazuma ulmifolia Lam. is a semi-deciduous, heliophytic, fast-growing and pioneer species, with natural occurrence in different forest formations, such as Seasonal semi-deciduous and deciduous Forests, Mixed Tropical Rainforests, Forested Savanna and Steppe Savanna. It belongs to the Malvaceae family, commonly known as "mutambo", "mutamba", "amoreira", "embira" and "fruta-de-macaco" (Carvalho, 2007). The flowering period occurs between August and January, and ripe fruits are noticed with higher concentrations from August to November, with peaks in September and October (Nunes et al., 2005; Paiva Sobrinho & Siqueira, 2008). The seeds of *G. ulmifolia* are rounded and grayish, with impermeable tegument with a natural dormancy and high longevity (Carvalho et al., 2006; Paiva Sobrinho et al., 2012).

When adult, the species reaches 30 m in height, with a diameter at breast height (dbh) from 30 to 60 cm (Carvalho, 2007; Motta et al., 2006). The wood has a compact color and tissue, little resistance, and it is used in boxes, carpentry, and production of barrels and butts of shotguns (Barbosa & Macedo, 1993; Carvalho, 2007; Lorenzi, 1992). Aside from providing material for rope manufacturing, the leaves can be used for cattle feeding, and the fruits are appreciated by monkeys and other animals (Carvalho, 2007). Regarding the rehabilitation of degraded areas, *G. ulmifolia* is considered to be a very important species (Lacerda & Figueiredo, 2009; Lima et al., 2009; Pereira et al., 2012; Rodrigues et al., 2010). The species can be included in the group of species of secondary formations and open young forests since it has a potential adaptation not only to humid soils but also to dry ones, compacted or with a sandy texture (Carvalho, 2007).

This study aims to evaluate the initial performance, up to 48 months after planting, of *G. ulmifolia* in a reforestation experiment in an agricultural area.

MATERIALS AND METHODS

This study was conducted in an area of 7.2 ha^{-1}, located in the municipality of Dois Vizinhos, southwestern region of the state, Iguazu River Basin, with central coordinates between 25º41'44"S and 53º06'07"W, altitude range from 475 to 510 m, in a region of Mixed Tropical Rainforest with the influence of Seasonal Semideciduous Forest. The region is inserted in the third plateau of Parana, with geological material originated from basalt. The region´s soil is nitosoil type. The climate is classified as humid subtropical mesothermic (Cfa), without a defined dry season and an average temperature of the warmest month of 22° C, based on the Köppen classification (Alvares et al., 2017). Historically, there is at least one frost every two years (Caramori et al., 2001).

We planted seventy native tree species, using a distance of 3 m between lines and 2 m between plants, in four plots of 54 x 40 m (Figure 1), in December 2010. In each plot, eighteen seedlings of *G. ulmifolia* were planted, 30 to 50 cm in height, totaling seventy-two plants. Every seedling received 36 g of NPK (5-20-10) as fertilization. In addition, each planting hole was irrigated with 2.5 L of water retention gel (HydroplanHyB™; 2.5 kg/1,000 L of water). The seedlings were protected with cardboard mulching and received annually a cover fertilization of 40 g of urea per plant. Biannually, weed control was done by slashing followed by chemical weeding, up to the third year. *G. ulmifolia* seeds were collected in Paranavaí-PR forests (approximately 270 km distant from the experimental site) and the seedlings were donated by the Instituto Ambiental do Paraná (IAP) nursery.

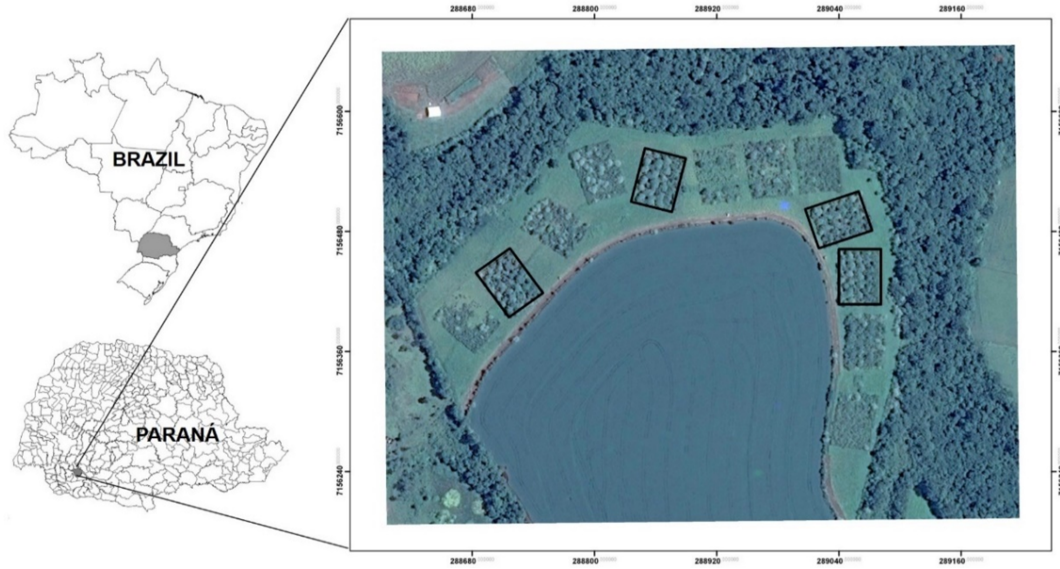

Figure 1 – Experimental area of ecologic restoration technologies located in Dois Vizinhos, Parana, Brazil. The plots highlighted as black rectangles correspond to the ones where *Guazuma ulmifolia* Lam was planted.

The site soil was classified by Franco (2016) as a dystrophic Red Nitisol (Bhering & Santos, 2008) and its characterization follows in Table 1 below.

Table 1 - Soil´s physical and chemical properties, at 0-20 cm depth, of the study area, 2010. Source: Franco (2016).

Depth	O.M.[1]	P[2]	K[3]	Ca[4]	Mg[5]	pH[6]	V[7]	WMD[8]	Density
cm	$g.dm^{-3}$	$mg.dm^{-3}$		$Cmolc.dm^{-3}$		CaCl2	%	mm	$g.dm^{-3}$
0-5	43.56	6.42	0.72	4.72	3.27	5.22	67.87	3.54	1.06
05-10	35.98	3.34	0.49	4.25	2.74	5.07	63.83	3.17	1.18
10-20	31.86	1.88	0.29	3.75	2.61	5.02	61.85	2.56	1.21

Where: [1] – O.M.: organic matter; [2] – P: phosphorus; [3] – K: potassium; [4] – Ca: calcium; [5] – Mg: magnesium; [6] – pH: hydrogen ionic potential; [7] – V: base saturation;[8] – WMD: weighted mean diameter.

The data were collected biannually, considering the following variables: survival (%), total height (m), root collar diameter (cm), crown projection area (m^2), crown height (m) and crown volume (m^3). The crown diameter was measured with two cross-line measurements, which were transformed into crown projection area using the ellipse area formula, as: Sc (m^2) = $dl.de.\pi/4$. Note: Sc is the crown projection area; dl and de are the measured crown diameters (m), respectively, in the line direction and in the planting interline.

The crown volume was estimated as an elliptical cylinder, multiplying the crown area by its length, as shown: $vc\ (m^3) = sc.ac$. Note: vc is the crown volume; sc is the crown area (m^2); ac is the crown length (m).

According to Terborch & Petren (1991), this method overestimates the real crown volume, but gives an estimate of the number of branches and leaves existent in the forest canopy (Montgomery & Chazdon, 2001).

In addition to the data collected regarding dendrometric variables, climate data from August 2010 to August 2014 were obtained from the University meteorological station, 1.380 m far from the experimental area. These data were utilized to explain the species behavior due to frost occurrence.

To study the growth in terms of collar diameter, total height, crown projection area and crown volume, the Gompertz model was fitted, represented by the following mathematical function (Scolforo, 1998): $Wt = Ae^{-be^{-kt}}$. The growth rate was obtained by the derivative of growth due to time: ∂W / ∂t = k W ln (A / W). Where Wt – plant size at time t; A – asymptotic value that the plant can reach; e – exponential; K – a relative measure of the plant´s growth rate; b – commonly without biological relevance, reflecting only the option by the time zero; t – age (months).

Statistical analyses were conducted using the Nonlinear Least Square (NLS) function available in the statistical program R, version 3.4.3, to obtain the coefficients and *t* value for each coefficient. The quality of the model fitting was analyzed through the standard error and adjusted coefficient of determination, obtained manually on the statistical program R.

RESULTS AND DISCUSSION

Plant survival percentage was found to be 96%, with a mortality of only 3 individuals (one individual died at 36 months, two at 42 months and three at 48 months). According to the climate data used (Figure 2), frosts occurred during the winter of 2011 and 2013. The 2011 frosts occurred in June, July and August, with absolute minimum temperatures under 3ºC. In 2013, the frosts occurred in July and August, with absolute minimum temperatures of 2.4 and -1.8ºC, respectively. Thus, it can be stated that frost was not the mortality cause at six months of age, and, apparently, it may have slightly affected the plants only at 36 months. This shows the species to be highly frost resilient.

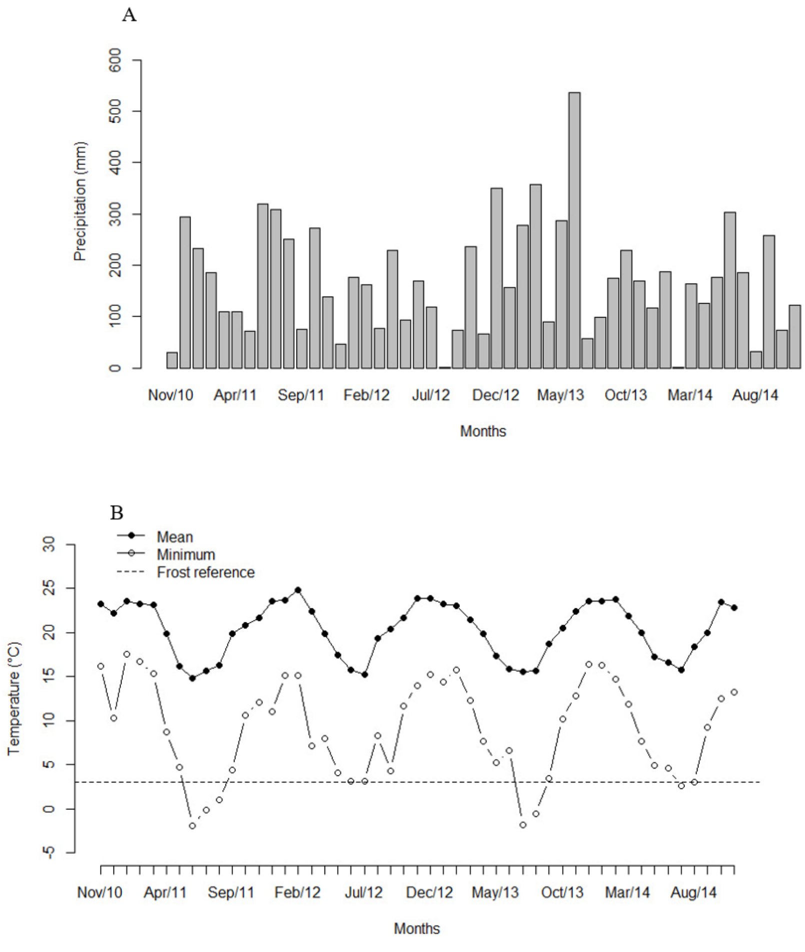

Figure 2 – A) Rainfall (mm), B) average temperatures (ºC) and absolute minimum temperatures (ºC) per month registered in the study area from December 2010 to November 2014. Data stemming from Meteorological Station at the Federal Technological University of Parana – Dois Vizinhos, Parana, Brazil.

Carvalho (1982), in a study about the silvicultural outputs of native forest species in Brazilian Southern subtropical forest, proposes adequate levels for the survival at the age of 84 months: high (≥ 70%), regular (≥ 50% ≤ 69%) and little (≤ 49%). So, the survival rate for *G. ulmifolia* was classified as "high", indicating that the species is tolerant of possible biotic and abiotic pressures in a plantation with several species. This is similar to the data of Alvarenga et al. (2016), where the authors found a survival rate of 100% for *G. ulmifolia* in a riparian forest planting in Minas Gerais. Other variables could have affected the low mortality, as the chosen silvicultural system, planting methods, after-care, and also the silvicultural behavior of the studied species (Carvalho, 1982). Concerning the field establishment, generally, it is a species with high survival and growth rates (Alvarenga et al., 2016; Melotto et al., 2009; Pereira et al., 2012).

The annual water balance (Figure 2A) revealed an annual water deficiency of 1.4 and 0.8 mm in August 2012 and February 2014, respectively. Even though there were high temperatures in periods with water deficiency, the beneficial water balance in other periods minimized possible stresses caused by heat (Figure 2B), since the transpiration process is an excellent mechanism of thermal regulation.

G. ulmifolia presented a good initial silvicultural performance at 48 months. The lower average values of growth in total height, root collar diameter, crown projection area and crown volume were noted at 12 and 36 months. The reduction in collar diameter growth at 12 months happened due to the series of frosts during winter; however, at 18 months, the species demonstrated a considerable increase in collar diameter growth (Figure 3A).

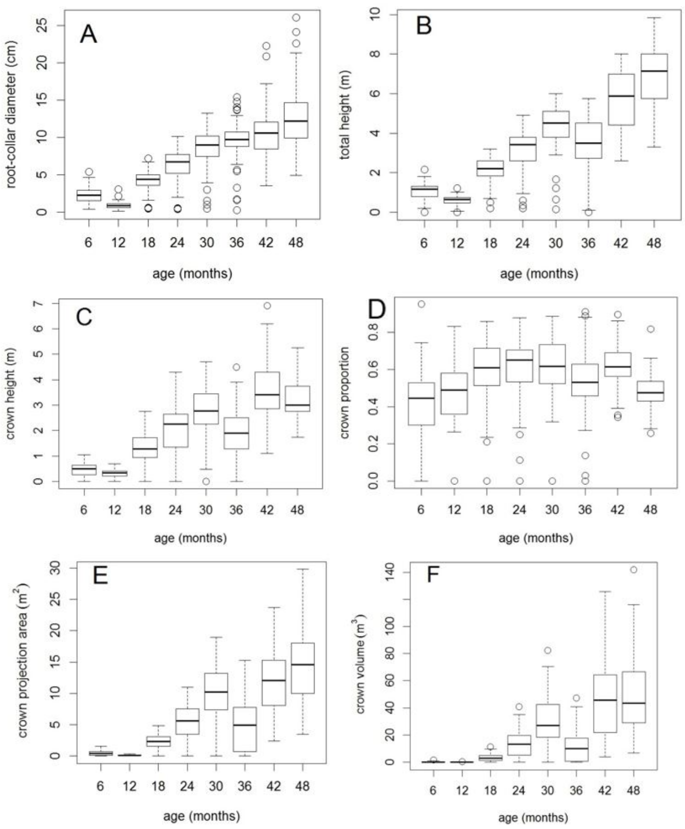

Figure 3 – Box graphics with values of root collar diameter (A), total height (B), crown height (C), crown proportion (D), crown projection area (E) and crown volume (F) of the individuals of *Guazuma ulmifolia* Lam. evaluated up to 48 months.

At 12 and 36 months, frost damaged the apex branches of some individuals, which decreased their heights (Figure 3B). By losing the apical dominance, the vegetative growth reduced the mean height, allowing the development of more than one lower branch (at the base). This proves that the species is not properly considered resistant but resilient to frosts, due to its sprouting potential. As reported by Wishnie et al. (2007), *G. ulmifolia* displays a better development in well-drained soils, has fast initial growth and shapes thick crowns and canopies after two years, supporting the results presented in this paper. The sprouting after frosts modified the species´ silvicultural behavior, which started to shade a greater area, proving that the buds could be beneficial once the ability to cover and shade the soil is a character of high importance to be considered when choosing a native tree species to promote forest succession (Wishnie et al., 2007).

Stolarski et al. (2018) observed the same behavior for *Trema micrantha* (L.) Blume, a pioneer species that occurs in different types of environments and forest ecosystems, usually associated with *G. ulmifolia*. *T. micrantha*´s collar diameter and height growth were reduced due to the frosts in the first year of establishment, which caused the apical dominance loss and the occurrence of sprouting activity, as a representation of the species resilience to cold weather.

Since susceptibility to frost and low temperatures is a criterion that must be considered in the selection of species for restoration projects, knowing the species frost tolerance/resilience and choosing a frost tolerant or resilient species is a key point for the project's success. For instance, other ecosystem associated-species to *G. ulmifolia* that are frost tolerant and could be chosen to arrange a restoration project in the southern region of Parana with *G. ulmifolia* are *Schinus terebinthifolius* and *Parapiptadenia rigida*, pioneer and early secondary species, respectively, and *Eugenia involucrata*, a late secondary species (Rorato et al., 2018).

The best results for all variables were achieved at 48 months of age, and it can be acknowledged that, after 36 months, trees of *G. ulmifolia* were already established in the region despite a reduction in height, crown projection area and crown volume caused by the intense frosts. The same was noticed for *T. micrantha*, which reached the highest values for collar diameter, total height, crown projection area and canopy volume at 42 months of age, when the species can be regarded as established (Stolarski et al., 2018).

The average crown volume was 49.86 m^3 (Figure 3F). The average of crown projection area registered in this period was 14.36 m^2 (Figure 3E), two times bigger than the planting spacing utilized, which was 6m^2, implying, thus, that the species was highly efficient in controlling invasive grasses, which is important for the establishment of new species in the understory (Chazdon, 2015; Elliott et al., 2013; Lamb et al., 2005).

The values of crown projection area and crown volume increased gradually over time (Figure 3E and 3F). There was an enhancement in the data range because of the different development levels of the species. Although there was a growth reduction provoked by climate and soil interferences, the graphic box at 12 months exhibit lower dispersion, revealing a median under the other periods´ values. The physiological damages to the cold susceptible individuals from May to September diminished vegetative growth, resulting in the death of the aerial part of some plants. Nonetheless, vegetative growth was induced by anatomical modifications in the cambium region (Souza et al., 1991).

There was no frost occurrence in 2012, after the first severe winter, so the plants grew normally. However, in 2013, frosts occurred again, and a reduction in total height growth, crown projection area and crown volume at 36 months was observed. Even with the susceptibility to frost, individuals of *G. ulmifolia* could get over the vegetation competition, through the growth of the uppermost canopy layer at the age of 42 months.

The allometric coefficients obtained for the regression test between the collar diameter and total height for *G. ulmifolia*, including the t significance test, coefficient of determination (R^2) and the relative standard error (Syx) are displayed in Table 2. It is possible to recognize that the fitted model for height explains most of the variation in collar diameter of the trees at 48 months. However, the coefficient of determination had different values, varying from 0.3184 to 0.8392 because of the heterogeneity of the data set of the studied species. Therefore, the equations with the highest coefficient of determination were the ones with the highest precision as well (Soares et al., 2011).

Table 2 - Statistical parameters of the linear model to estimate the collar diameter related to the total height of *Guazuma ulmifolia* at different ages.

Age (months)	B_0	t value	B_1	t value	R^2	Syx (%)
6	0.3187	1.847 ns	1.8542	12.141 ***	0.6797	25.17
12	0.2159	1.796 ns	1.0905	5.910 ***	0.3233	42.73
18	0.4791	1.585 ns	1.7568	12.832 ***	0.6974	17.89
24	0.5455	1.720 ns	1.8401	19.280 ***	0.8392	13.13
30	1.1744	1.711 ns	1.7127	11.213 ***	0.6373	16.96
36	5.3684	8,042 ***	1.2152	6.680 ***	0.3839	22.58
42	2.7120	1.967 ns	1.3380	5.765 ***	0.3184	28.41
48	-0.4754	-0.268 ns	1.9016	7.552 ***	0.4554	25.20

Where: B_0: intercept in y; B_1: slope of the axis; R^2: coefficient of determination; Syx (%): relative standard error. ANOVA (*P = 0.05; **P = 0.01; ***P = 0.001; ns = non-significant).

The fitted function for collar diameter, height and crown projection area are associated with high values of the standard error of the estimate, which varied, respectively, from 13.13% to 42.73% (Table 2), 24.57% to 54.50% (Table 3), and 26.24% to 70.12% (Table 4). The standard error determines the setting accuracy, that is, the lower the standard error, the best its accuracy is. The significant standard error could be a result of the non-uniformity of the data set, which affected directly the functions´ fitting.

Table 3 - Statistical parameters of the linear model to estimate the crown projection area regarding the total height of the species *Guazuma ulmifolia* at different ages.

Age (months)	B_0	t value	B_1	t value	R^2	Syx (%)
6	-0.3378	-4.415 ***	0.7678	11.333 ***	0.6488	54.50
12	-0.0336	-1.642 ns	0.2561	8.164 ***	0.4805	52.36
18	-0.8367	-3.289 **	1.4720	12.775 ***	0.6956	27.76
24	-1.6466	-3.171 **	2.2809	14.595 ***	0.7491	24.57
30	-1.7394	-1.313 ns	2.7446	9.312 ***	0.5470	27.27
36	-2.4592	-3.029 **	2.2804	9.981 ***	0.5849	51.77
42	-3.1343	-1.940 ns	2.5941	9.533 ***	0.5660	29.42
48	-4.3680	-1.919 ns	2.6960	8.348 ***	0.5062	28.74

Where: B_0: intercept in y; B_1: slope of the axis; R^2: coefficient of determination; Syx (%): relative standard error. ANOVA (*P = 0.05; **P = 0.01; ***P = 0.001; ns = non-significant).

Table 4- Statistical parameters of the linear model to estimate the crown projection area regarding the collar diameter of the species *Guazuma ulmifolia* at different ages.

Age (months)	B_0	t value	B_1	t value	R^2	Syx (%)
6	-0.2588	3.134 **	0.3202	9.516 ***	0.5648	60.65
12	0.4440	2.180 *	0.8810	4.262 ***	0.1947	65.19
18	-0.5705	-2.197 *	0.6745	11.501 ***	0.6490	29.81
24	-1.6694	-3.203 **	1.1368	14.581 ***	0.7488	24.59
30	-1.3207	-1.128 ns	1.3357	10.214 ***	0.5927	26.24
36	-1.9874	-1.303 ns	0.7397	4.786 ***	0.2384	70.12
42	2.5689	1.645 ns	0.8847	6.223 ***	0.3535	35.91
48	1.7018	1.137 ns	0.9899	8.800 ***	0.5329	27.95

Where: B_0: intercept in y; B_1: slope of the axis; R^2: coefficient of determination; Syx (%): relative standard error. ANOVA (*P = 0.05; **P = 0.01; ***P = 0.001; ns = non-significant).

From the equation coefficients generated to estimate the collar diameter regarding the total height, it can be perceived that these were significant ($p>0.001$) for the slope of the axis, implying that the rise in one unity of height induces the rise in diameter. At the age of six months, the allometric pattern is similar to the one observed for the species at the age of 24 months, which showed a better diameter development.

The allometric relation between diameter and height was discontinuous at 12 months of age. It is suggested that the alterations in growth patterns are related to frost occurrence, which reduced the development and resulted in the death of some of the aerial parts of some individuals of *G. ulmifolia*, leading to new growth of the trunk system.

At the age of 12 months, a preferential development in height occurred. From 18 months on, a continuous growth was registered which was then reduced at 42 months; a time when the growth in height and collar diameter reached a balance (Figure 3A and 3B). This indicates that *G. ulmifolia* tends to invest more in diameter growth than in height. Probably the investment in sustenance (diameter) of the species is connected to the stem ability in supporting the plant structure, resisting to its mass and to the wind strength (Fontes, 1999; Sterck & Bongers, 1998), which is intensified in open environments, edges and forests corridors (Santos et al., 2012). Consequently, the increase in diameter is directly related to the size; in other words, it means that the higher the tree and the dimension of its crown, the higher the mass, and it is necessary to increment the diameter in order to support all of its structure.

This indicates that the boost in diameter in a plant occurs as far as it grows, demanding stronger support (Sterck & Bongers, 1998). However, when the individuals reach a large size, the proportion of height for a certain circumference tends to stabilize, that is, the growth becomes continuous in the two dimensions (Fontes, 1999).

In Table 3, the allometric coefficients obtained by the regression between crown projection area and total height at 48 months, including the t significance test, coefficient of determination (R^2) and the relative standard error (Syx) are displayed. It is noticed that height could describe most of the variation in the crown area over the time; still, the coefficients of determination revealed variation (0.4805 and 0.7491) as a consequence of the non-uniformity of the data set of the species evaluated. The biggest coefficients of determination were observed at 18 and 24 months of age.

G. ulmifolia performed better in height growth at six months of age, investing less in crown projection area rates, though. The species registered the higher growth in height at 12 months compared to the crown projection area. There was a continuous rise in the investment of the crown projection area in the following months, resulting in the largest increment at 30 months, with a reduction in the next months, keeping the allometric relation (crown projection area and height) through constant levels of growth.

The species enhanced height significantly during the initial period up to 30 months of age when compared to other periods. This behavior can be specific of the species, which tries to guarantee individual space in the canopy during the vegetation development and thickening (Fontes, 1999), or it can even be associated with ecological variables that have induced a change in growth strategy (Portela & Santos, 2003).

Once the species expanded its size in height, it starts to invest in growth in the crown area as a result of higher light penetration caused by the lower density of tree vegetation, which allowed for the existence of lower live branches (Siqueira, 2006) and occupation of the horizontal space (Costa et al., 2012).

On the other hand, the canopy structure enlarged the crown competition for light, benefiting the upper branches instead of the lower ones (Siqueira, 2006), requiring more investments in height of the individuals seeking light. Another hypothesis is related to the development level of some individuals that would have already developed crowns similar to the ones shaped when adult, so the crown area enlargement in advanced periods would be inferior.

G. ulmifolia attained the best performance in collar diameter from 12 months, with continuous growth in crown projection area from 18 months onwards (Table 4), yielding the largest increment at 30 months, decreasing in the following months, keeping the allometric relation (crown projection area and collar diameter) in constant levels of growth. González-Tokman et al. (2018), with eleven species in a forest restoration area, also observed that *G. ulmifolia* presented high crown volume and area in the first years after planting compared to the other species used.

Santos et al. (2012) stated that the different behavior shown by the species in forest environments can be explained by the regeneration groups to which they belong and by the strategies adopted to gather resources necessary for their development. Also, Siqueira (2006) states that the fact that tree individuals fit better into distinct allometric models for each environment suggests that the ecological factors could have a restrictive role in the allometry of each species.

Therefore, it is suggested that the variation registered in allometry is a result of the specificity of each species, which can be caused by seasonal natural or sporadic events, requesting immediate answers from the individual regarding the strategy to be chosen. It is a decision that is already well established in populations that play the same role in a given ecosystem and occupy the same ecological niche.

The great initial growth development of *G. ulmifolia*, as observed in this study is an important feature for restoration projects due to its relevance for the establishment of other species. As a pioneer species, it is essential to create an adequate environment for late-species development. Its fast growth and shade provide soil protection and microclimate conditions required for late-successional species settlement (Plath et al., 2011; Pereira et al., 2012), such as *Tabebuia rosea* and *Cedrela odorata*, two valuable timber species (Plath et al., 2011). Besides, its good performance in height and collar diameter growth and survival is a fundamental characteristic that can be used for the establishment of integrated systems of forestry and cattle as well (Melotto et al., 2009)

In addition, *G. ulmifolia* can be referred to as a protective species in the regeneration process (Lima et al., 2009) or as a nurse tree for the succession of Meso-American seasonal forests on abandoned pastureland (Griscom, 2004). Thus, *G. ulmifolia* is a species that can be used to initiate forest succession in the ecosystems where it naturally occurs.

CONCLUSION

G. ulmifolia demonstrated a satisfactory development over time, reducing its growth only due to the occurrence of severe frosts in the region. The species´ growth at the age of 4 years, combined with its high survival rate and sprouting capacity, confers an excellent performance in the region, and it can be recommended to be utilized as a shade species for fast canopy establishment in forest ecological restoration projects, especially in subtropical regions with frost occurrences.

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