MINERAL NUTRITION IN THE TREE *Calophyllum brasiliense* Cambess. (Calophyllaceae)[1]

Paulo Sérgio Morandi[2]*, Simone Matias Reis[3], Beatriz Schwantes Marimon[4], Claudinei Oliveira-Santos[5], Edmar Almeida Oliveira[2], Bianca Oliveira[5], Pábio Henrique Porto[5] and Ben Hur Marimon-Junior[4]

[1] Received on 08.12.2014 accepted for publication on 24.04.2017.
[2] Universidade do Estado de Mato Grosso, Doutorado em Biodiversidade e Biotecnologia, Nova Xavantina, Mato Grosso, Brasil. E-mail: <morandibio@gmail.com> and <edmardinei@hotmail.com>.
[3] Universidade do Estado de Mato Grosso, Programa de Pós-Graduação em Biodiversidade e Biotecnologia, Nova Xavantina, Mato Grosso, Brasil.. E-mail: <simonematiasreis@gmail.com>.
[4] Universidade do Estado de Mato Grosso, Departamento de Ciências Biológicas, Nova Xavantina, Mato Grosso, Brasil. E-mail: <biamarimon@hotmail.com> and <bhmjunior@gmail.com>.
[5] Universidade do Estado de Mato Grosso, Mestrado em Ecologia e Conservação, Nova Xavantina, Mato Grosso, Brasil.. E-mail: <claudineisantosnx@gmail.com>,<bibica_89@hotmail.com> and <pabioporto.net@gmail.com>.
*Corresponding author.

ABSTRACT – Riparian and gallery forests located at the "arc of deforestation" have been undergoing fast degradation. With the implementation of the new Brazilian Forest Code (Law 12,651 of 2012), these can be reduced further. Thus, new studies on seedling production for ecological restoration should be carried out using native species from the Amazon and Cerrado. The objective of the present study was to assess under which shading levels the seedlings of *Calophyllum brasiliense*, a tree species typical of humid environments, show the highest values of growth and nutrient use efficiency, aiming at using these seedlings for restoration. The study was carried out in a plant nursery of the State University of Mato Grosso in Nova Xavantina, Brazil. We assessed seedling growth in diameter, height, number of leaves, production of shoot and root dry mass, Dickson quality index (DQI), and efficiency in the internal use of nutrients (EIUN) in greenhouses at 0 (full sunlight), 30, 50, 70, and 90% shading. The treatments at 50 and 70% shading showed the best results. Ecologically, the species responds well under both gap conditions (50% shading) and canopy or closing gap conditions (70% shading). Our results showed that the ideal conditions to produce seedlings of this species with high EIUN are obtained in greenhouses with 70% shading.

Keywords: Nutrient use efficiency; Early development; Seedling production.

INFLUÊNCIA DA DISPONIBILIDADE DE LUZ NA QUALIDADE DE MUDAS E NUTRIÇÃO MINERAL DE Calophyllum brasiliense Cambess. (Calophyllaceae)

RESUMO – As florestas ciliares e de galeria localizadas no "arco do desmatamento", vêm sofrendo degradação acelerada e, com a implantação do novo Código Florestal Brasileiro (Lei nº 12.651 de 2012), essas poderão ser reduzidas ainda mais. Diante desse fato, novos estudos acerca da produção de mudas para recuperação de áreas degradadas devem ser realizados com espécies nativas do domínio Amazônico e também do Cerrado. Por conseguinte, o objetivo do presente trabalho foi verificar em quais níveis de sombreamento, mudas de ***Calophyllum brasiliense****, espécie típica de ambientes úmidos, apresentam os valores mais adequados de crescimento e eficiência de uso interno de nutrientes, visando a recomposição de áreas perturbadas. O estudo foi desenvolvido em viveiro florestal da UNEMAT de Nova Xavantina-MT. Avaliamos o crescimento das mudas em diâmetro, altura, número de folhas, produção de massa seca aérea e radicular, Índice de Qualidade de Dickson (DQI) e a Eficiência no Uso Interno de Nutrientes (EIUN) em casas de vegetação a 0 (pleno sol), 30, 50, 70 e 90% de sombreamento. De forma geral, os melhores resultados foram obtidos nos sombreamentos a 50 e 70%. Ecologicamente, a espécie responde melhor tanto em condições de clareira (50% de sombreamento) quanto em condições de dossel ou fechamento de clareira (70%). Nossos resultados demonstraram que as condições ideais para a produção de mudas desta espécie e maior EIUN, podem ser obtidas em condições de viveiro com 70% de sombreamento.*

Palavras-chave: Eficiência no uso interno de nutrientes; Desenvolvimento inicial; Produção de mudas

Revista Árvore. 2017;41(2):e410216
http://dx.doi.org/10.1590/1806-90882017000200016

1. INTRODUCTION

The gallery forests of the Cerrado (Brazilian savanna) have been undergoing fast degradation (Lopes and Schiavini, 2007). The scenario is especially critical in the region known as "arc of deforestation," in areas adjacent to the Amazon Forest, where the advancement of agricultural and farming activities represents a serious threat to the native vegetation (Marimon et al., 2014). Besides, with the implementation of the new Brazilian Forest Code (Law 12,651 of 2012), ciliary and gallery forests can undergo even faster reduction, as the length of permanent protection areas (PPAs) is now considered from the regular river channel and not from the full river flow anymore. Soares-Filho et al. (2014) estimated for the state of Mato Grosso, with the new Forest Code, a reduction of approximately 506 thousand ha of ciliary or gallery forests. This reduction can result in important losses of biodiversity and ecosystem services regarding water quality.

This scenario requires attention and special care for the preservation of gallery forests and recovery of degraded areas in the Cerrado biome, in particular in areas adjacent to the Amazon. However, those actions require knowledge of the early development of native species, mainly in terms of the variation in light availability and plant capacity to accumulate biomass efficiently through nutrient use (Chapin, 1980; Vitousek, 1982; Reis et al., 2015).

Cerrado soils usually have low nutrient availability, which directly interferes with the process of mineral nutrition in plants. In addition, mineral nutrition efficiency varies among species (Chapin, 1980; Haridasan, 2008; Bündchen et al., 2013). Vigorous plants that have low concentration of nutrients in their tissues should not be considered sick, but efficient in the internal use of nutrients under the conditions where they live (Chapin, 1980).

Low concentration of nutrients is not only observed in the senescent tissue, but also in the live tissue, in plants with high growth vigor (Reis et al., 2015). These authors observed that the best quality of seedlings grown in nurseries seems to be associated with the physiological capacity of plants to use nutrients at low concentration in the live leaf tissue, showing high efficiency in the use of this resource. This sort of information is essential to develop seedling production models suitable for the restoration of disturbed forests (Almeida et al., 2004). Moreover, it also sets the ground for further studies on the ecophysiology of tree species as a function of ambient light (Alvarenga et al., 2003).

The light condition where the plant grows is important because light capture efficiency depends on the capacity of the plant to adjust its photosynthetic apparatus to the ambient (Silva et al., 2007). Plants exposed to excessive radiation can undergo reduction in photosynthetic activity, a physiological process characterized as photoinhibition (Dias and Marenco, 2006). As the *Calophyllum brasiliense* Cambess. (Calophyllaceae) is a late-growth species (Swaine and Whitmore, 1988), in habitats with high insolation its seedlings may have difficulty to grow and acclimatize due to the photoinhibition (Dias and Marenco, 2006).

Plants under suitable conditions (Kylafis and Loreau 2011), mainly in terms of light incidence, should incorporate greater biomass, as their physiological processes work more efficiently. Those processes, such as nutrient absorption and production of photoassimilates, are greatly influenced by environmental conditions (Lima-Junior et al., 2005; Taiz and Zeiger, 2009).

Therefore, our objective was to test under which shading levels seedlings of *Calophyllum brasiliense* show the most suitable values of growth and nutrient use efficiency to support seedling production high enough to supply the restoration of disturbed areas. Our hypothesis is that *C. brasiliense* shows better early development and nutrient use efficiency at high shading levels, as it is a late-growth species.

2. MATERIAL AND METHODS

2.1. Study area and species

The present study was carried out in the forest nursery of the State University of Mato Grosso (UNEMAT), at the Nova Xavantina Campus, state of Mato Grosso (14º41'S and 52º20'W; 306 m a.s.l.), located in the Bacaba Municipal Park (PMB). In the Köppen system, the climate of the region is type Aw, with two well-defined seasons, a rainy season that begins in September/October and can extend until March/April and a dry season that starts in April/ May and goes until September/October (Silva et al., 2008). The average annual rainfall varies between 1,300 and 1,500 mm, and the average annual temperature is 25 ºC (Marimon et al., 2010). During the study period, the rainfall and average temperature data followed the trend of the region; the rainfall varied from 0 and 280 mm and the temperature, from 20.5 to 28.5 °C.

The native tree species *Calophyllum brasiliense* (family Calophyllaceae, former Clusiaceae or Guttiferae), locally known as *guanandi*, *olandi*, and *jacareúba*, (Lorenzi, 2008), has broad distribution in Brazil and is typical of wetlands. It occurs in the Atlantic Forest, flooded forests in the Amazon, in the fringe of mangrove forests in the Caatinga, and gallery forests in the Cerrado (Lorenzi, 2008; Oliveira-Filho; Ratter, 1995). Its wood is used in the construction of buildings, fluvial construction, woodworking, production of canoes, floors, plywood, paper, and wine barrels (Carvalho, 2003; Lorenzi, 2008). The species is also used in the urban tree planting of squares, streets, and avenues (Carvalho, 2003).

2.2. Sampling design and data collection

We collected seeds from different trees in a gallery forest in the Bacaba Municipal Park in August 2008 (same year of the experiment). We selected perfectly healthy seeds with no predation signs to assure the germinative vigor. The seeds remained in a recipient with water for approximately four hours, and shortly after that, part of the integument was removed to accelerate germination. We used a substrate composed of weathered wood sawing and Red Latosol at the proportion 2:1, respectively. Then, we added 400 g of N-P-K 4-30-16 granular chemical fertilizer and corrected soil acidity with 2 kg of dolomitic limestone (PRNT 90%) for each cubic meter of substrate to improve the chemical attributes and meet the basic nutritional requirements of plants. The substrate showed the following properties: pH (H_2O): 6.7, phosphorous (P): 24.9 mg dm^{-3} (Mehlich I method), potassium (K^+): 167 mg dm^{-3}, calcium (Ca^{2+}): 1.6 $cmol_c$ dm^{-3}, magnesium (Mg^{2+}): 0.53 $cmol_c$ dm^{-3}, aluminum (Al^{3+}): 0.0 $cmol_c$ dm^{-3}, Base Sum (BS): 2.9 $cmol_c$ dm^{-3}, Cation Exchange Capacity (CEC): 3.6 $cmol_c$ dm^{-3}, Organic Matter (OM%): 10.2 g dm^{-3}, Base Saturation (V%): 80.5, and Ca/Mg ratio: 3.01. After mixing the substrate with an electric concrete mixer for a perfect homogenization, we filled the seedling bags and applied an extra dose of 1 g of coated triple superphosphate to each bag to compensate the P fraction of the substrate inhibited by the alkaline action of the limestone.

The seedling treatments followed Marimon et al. (2008): 0% (full sunlight - FS), 30%, 50%, 70%, and 90% shading provided by a nylon screen (Sombrite®). We sowed directly in 15 x 30 cm black polyethylene bags with lateral holes. This method avoids seedling transplantation after germination, which is common in this sort of studies, and, therefore, prevents seedling loss and delay in the early development and saves time and costs with workforce.

We assessed 50 seedlings per treatment, watered daily (once a day). We considered germinated the seeds that showed an elongation of the hypocotyl over the soil and the appearance of at least one foliole. We measured the height to the apical bud with a transparent millimeter ruler, setting the zero point at the substrate level. We measured the collect diameter with a digital caliper (precision of 0.02 mm) and counted the number of leaves at 90, 150, 180, 210, 240, and 270 days after sowing (DAS). After the last measurement, we picked at random ten seedlings of each treatment to quantify the shoot and root dry biomass. We separated the roots from the shoot and then removed the substrate by washing it with water. The root and shoot were dried in an oven at 80 °C to constant weight and weighed on a precision scale. We assessed the quality of seedlings with the Dickson Quality Index (DQI) (Dickson et al., 1960), using the formula: DQI = TDM/((H/D) + (SDM/RDM)), where: TDM = total dry mass (g); H= shoot height (cm); D= stem diameter (mm); SDM= shoot dry mass (g) and RDM= root dry mass.

Based on the method described in EMBRAPA (1999), we determined the concentration of the nutrients N, P, K, Ca, Mg, and S in the leaf tissue of *Calophyllum brasiliense* for each shading level. N was determined by Kjeldahl distillation, K by digital image-based flame emission spectrometry, P and S by UV-VIS spectrophotometry, and Ca and Mg by atomic absorption spectrophotometry. We submitted the samples to wet triacid digestion in digestion blocks at 320 ºC to extract macronutrients.

For the calculation of the nutrient use efficiency (NUE), we adopted a methodology adapted from Vitousek (1982). In this method, the NUE is determined by the inverse of the concentration of each element in the tissues of senescent leaves. It is based on the equation: NUE = (gm. $(gn)^{-1}$), where: gm is the dry biomass of a sample in grams, and gn is the amount of nutrient, in grams, found in the same sample. This method applied to species that have no senescent leaves during the seedling phase is denominated efficiency in the internal use of nutrients (EIUN – Reis et al., 2015) according to the assumptions of Marimon-Junior et al. (unpublished data). Hence, the higher is the EIUN value, the higher is the plant capacity to convert absorbed nutrients into biomass unit.

2.3. Data analysis

We compared seedling development among treatments with an analysis of variance (one-way ANOVA), followed by a Tukey test at 5% significance level whenever necessary. For data that did not meet test assumptions, we used a Welch test (F test), which is a non-parametric analysis of variance, also using a Tukey *post hoc* test (Zar 2010). To test data normality and homoscedasticity assumptions, we used the Shapiro-Wilk and Levene tests, respectively. We also calculated linear regressions to assess the behavior of plants in relation to shading and selected the models with greater adjusted R^2 values. We performed all tests in the programs Past (Hammer et al., 2001) and R (R Development Core Team, 2014).

3. RESULTS

The highest diameter averages at 150 (4.69 mm), 180 (5.77 mm), and 210 (6.11 mm) days after sowing (DAS) recorded at 70% shading differed ($p<0.05$) from the values at 90 and 30% shading. The latter differed only at 180 DAS (Table 1). The highest stem diameter averages recorded at 240 (8.17 mm) and 270 (7.82 mm) DAS also occurred at 70% shading, which differed from all treatments ($p<0.01$) at 240 DAS.

Seedling development in height was significantly higher at 70 and 90% shading during the entire experiment (Table 1). It is worth mentioning that the treatment 70% shading at 240 DAS showed the highest height average (41.36 cm) and differed from almost all treatments ($p<0.01$), except for the treatment 90% shading.

Seedlings at 70% shading showed the highest averages of number of leaves in all measurements (Table 1). Curiously, the plants in that treatment usually showed a larger number of leaves than in the treatments at 50 and 90% shading, but never higher than in the treatments at full sunlight and 30% shading.

The root dry mass (RDM), shoot dry mass (SDM), and total dry mass (TDM) showed the highest averages at 50 and 70% shading (Table 2) and a cubic distribution for the variation in shading (Figure 1 A, B, and C). The SDM averages were always higher than those of RDM (Table 2). The lowest averages of the RDM/SDM ratio were observed at 70 (0.44) and 90% (0.29) shading. The RDM/SDM ratio at 90% shading differed from all other treatments ($p<0.05$) (Table 2). Besides, the RDM/SDM ratio showed a decreasing linear regression with the increase in shading (Figure 1D).

Considering the quality of seedlings, we recorded the highest values of height/stem diameter ratio (H/SD) in the treatments at 70 and 90% shading (Table 2). We also recorded the best height/shoot dry mass ratio (H/SDM) at 70% shading, but in this case, there was no significant difference. We recorded the highest values of the Dickson Quality Index (DQI) at 50 and 70% shading, and only the former differed significantly ($p<0.05$) from the treatment at 90% shading (Table 2).

The nutrients with the highest concentration in the leaf tissue of seedlings were N, Ca, and K. The averages of N and K did not differ among treatments. The concentration of P, Ca, and Mg responded inversely to shading (Table 3), but only Ca and Mg responded linearly to the reduction in radiation (Figure 2 A and B). The highest values of S occurred in environments with intermediate shading (50 and 70%).

The incorporation of biomass per unit of nutrient absorbed was positively influenced by the increase in shading and reached the highest value at 70% shading (Table 3). In this treatment, the efficiency in the internal use of nutrients (EIUN) for the accumulation of biomass in *Calophyllum brasiliense* seedlings differed from the treatments under a lower shading for almost all nutrients, except for S (Table 3). The EIUN of seedlings at 70% shading was almost three-fold higher than that of seedling at full sunlight and twice higher than that of seedlings at 30% shading. The nutrients Mg, P, and S contributed the most to the incorporation of biomass, and P and S showed a positive linear relationship with the increase in shading (Figure 2 C and D).

4. DISCUSSION

Stem diameter and height increased with shading in *Calophyllum brasiliense.* The treatment at 70% shading was the best for the structural input of seedlings. An intermediate light availability might have favored

Table 1 - Average values of stem diameter, height, and number of leaves of *Calophyllum brasiliense*, under different levels of shading (Shading) in a forest nursery. DAS= days after sowing, FS= full sunlight.

Tabela 1 - *Valores médios do diâmetro do coleto, altura e número de folhas das mudas de* ***Calophyllum brasiliense****, sob diferentes níveis de sombreamento (Shading) em viveiro florestal. DAS= dias após a semeadura, FS= pleno sol.*

DAS	Shading (%)	Stem(mm)	Height (cm)	Number of leaves
	FS	3.95a	12.62b	10.10a
	30	3.32bc	13.89bc	10.25a
90	50	3.48ac	12.88b	8.83a
	70	3.63ac	17.10ac	10.29a
	90	2.79b	18.04a	9.05a
	FS	4.24ab	15.78b	11.32ab
	30	4.26ab	15.46b	11.88ab
150	50	4.16ab	16.11b	11.07b
	70	4.69a	23.23a	13.70a
	90	3.79b	23.17a	10.89b
	FS	4.88ab	17.49b	13.76a
	30	4.67b	18.42b	14.00a
180	50	4.70b	19.87b	13.57a
	70	5.77a	26.96a	15.52a
	90	4.46b	25.99a	12.87a
	FS	5.28ab	26.18ab	15.75a
	30	5.15ab	21.78b	15.56a
210	50	5.17ab	23.39bc	15.03a
	70	6.11a	31.83a	17.03a
	90	4.87b	29.98ac	13.97a
	FS	5.87bc	23.64b	17.72ab
	30	6.55b	27.73bc	17.84ab
240	50	6.00bc	28.71bc	18.11ab
	70	8.17a	41.36a	18.94a
	90	5.37c	35.13ac	15.34b
	FS	6.33b	24.05b	17.65a
	30	6.90ab	33.24a	17.81a
270	50	7.77a	33.88a	17.45a
	70	7.82a	39.52a	18.87a
	90	6.32b	39.60a	16.82a

Average values followed by the same letter did not differ statistically from each other (α= 5%) by Tukey test.

Table 2 – Distribution of the root dry mass (RDM), shoot dry mass (SDM), total dry mass (TDM), and root/shoot ratio (R/S), Dickson Quality Index (DQI), height/shoot dry mass (H/SDM), height/stem diameter (H/SD), and shoot dry mass/root dry mass (SDM/RDM) in *Calophyllum brasiliense*, under different levels of shading (Shading) in a forest nursery. FS= full sunlight. SQP= seedling quality parameters.

Tabela 2 *– Distribuição de massa seca da raiz (RDM), aérea (SDM), total (TDM) e da relação raiz/parte aérea (R/S) e Índice de Qualidade de Dickson (DQI), altura/massa seca da parte aérea (H/SDM), altura/diâmetro do coleto (H/SD) e massa seca da parte aérea/massa seca da raiz (SDM/R) de* ***Calophyllum brasiliense****, sob diferentes níveis de sombreamento (Shading) em viveiro florestal. FS= pleno sol; SQP= parâmetros de qualidade da muda.*

Shading (%)	Dry matter weight (g)				SQP and DQI			
	RDM	SDM	TDM	R/S	H/SDM	H/SD	SDM/R	DQI
FS	3.13ab	5.72b	8.85b	0.56a	5.42a	3.74c	1.85b	1.62ab
30	4.95ab	9.62ab	14.57ab	0.53a	6.29a	4.99bc	2.08b	2.09ab
50	6.95a	14.43a	21.38a	0.50a	3.50a	4.23bc	2.10b	3.52a
70	6.94a	16.29a	23.23a	0.44a	2.90a	5.14b	2.37b	3.14a
90	2.79b	10.09ab	12.88ab	0.29b	5.10a	6.31a	3.76a	1.29b

Average values followed by the same letter did not differ statistically from each other (α= 5%) by Tukey test.

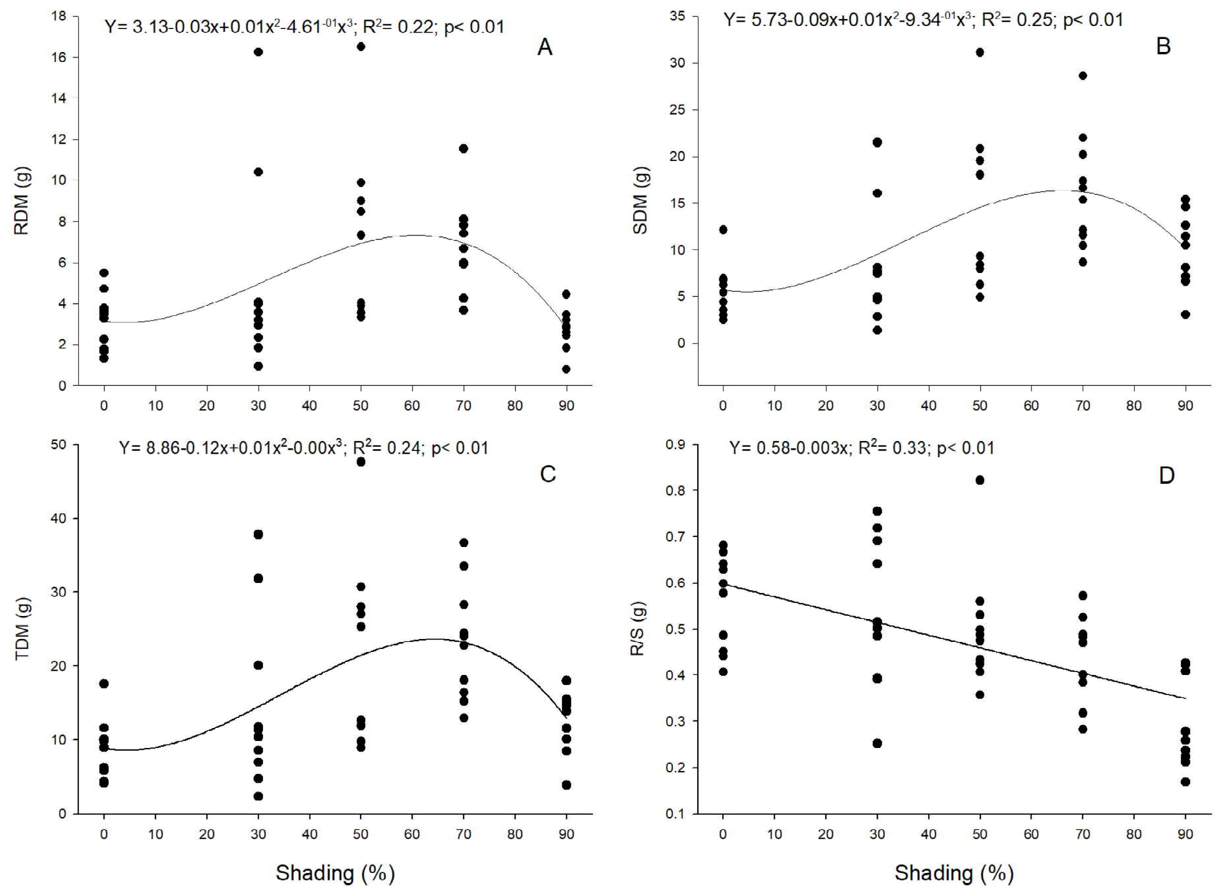

Figure 1 – Distribution of root dry mass (A), shoot dry mass (B), total dry mass (C), and root/shoot ratio (D) of *Calophyllum brasiliense*, under different levels of shading in a forest nursery.
Figura 1 *– Distribuição de massa seca da raiz (A), parte aérea (B), total (C) e da relação raiz/parte aérea (D) de* ***Calophyllum brasiliense****, sob diferentes níveis de sombreamento, em viveiro florestal.*

Table 3 – Nutrient concentration ($g.kg^{-1}$) and efficiency in the internal use of nutrients (EIUN) in the leaf tissue of *Calophyllum brasiliense*, under different levels of shading (Shading) in a forest nursery. FS= full sunlight.
Tabela 3 *– Concentração de nutrientes ($g.kg^{-1}$) e eficiência no uso interno de nutrientes (EIUN) no tecido foliar de mudas de* ***Calophyllum brasiliense****, sob diferentes níveis de sombreamento (Shading) em viveiro florestal. FS= pleno sol.*

Shading (%)		N	P	K	Ca	Mg	S
FS	Nutrient concentration	11.69a	3.23ac	5.87a	9.49a	1.80a	1.71bc
30		11.36a	3.68a	5.96a	9.42a	1.70ab	2.64a
50		11.89a	2.97ab	5.81a	8.42ab	1.68ab	2.19ac
70		11.53a	2.69bc	6.08a	7.70b	1.56ab	2.19ac
90		11.74a	2.33b	6.04a	7.94b	1.53b	1.40b
FS	EIUN	488b	1804b	992b	606b	3195b	3517a
30		851ab	2884bc	1611ab	1039bc	6162ab	3818a
50		1234a	4903ab	2483a	1699ac	8450ab	6829a
70		1416a	6438a	2692a	2167a	10977a	8047a
90		866ab	5272ac	1683ab	1304ab	6786ab	8062a

Average values followed by the same letter did not differ statistically from each other (α= 5%) by Tukey test.

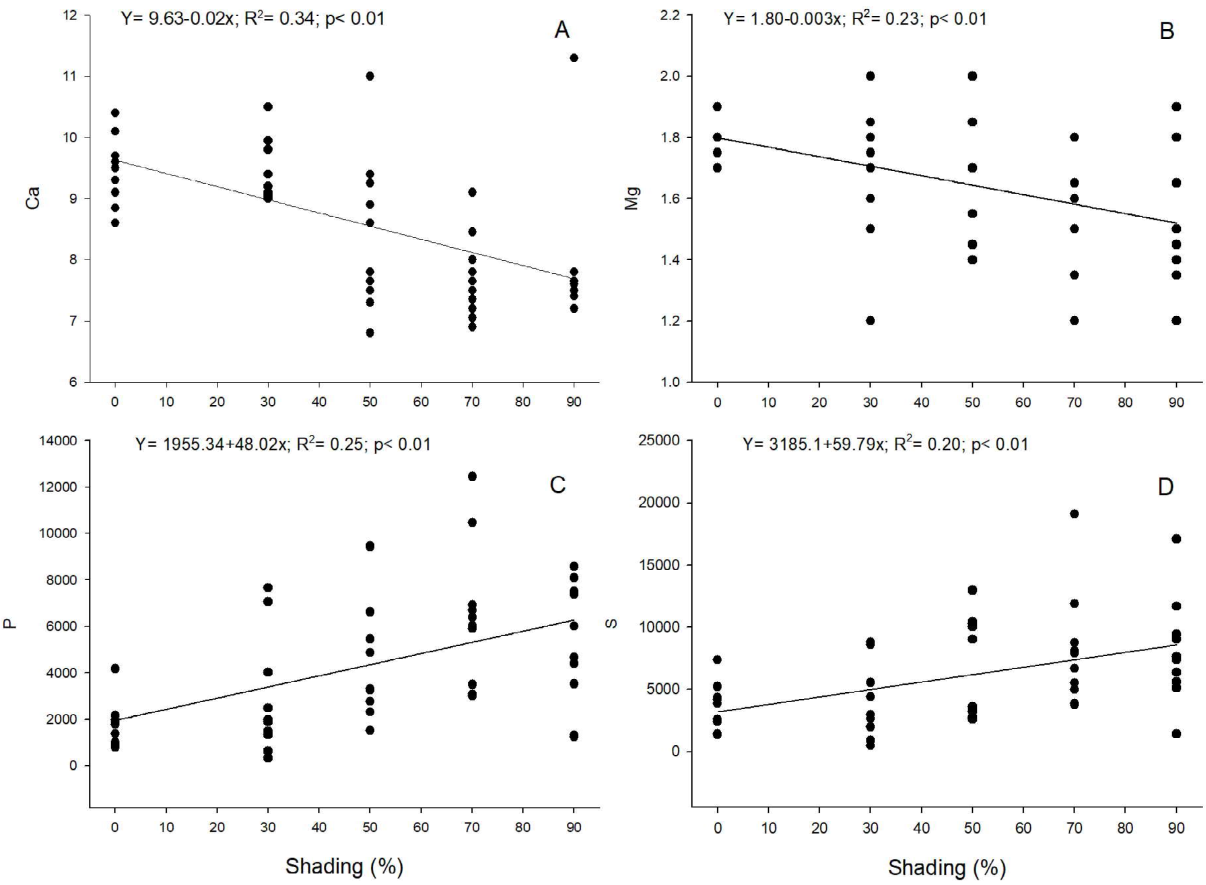

Figure 2 – Effect of shading on the concentration of Ca and Mg (A and B) and the efficiency in the internal use of P and S (C and D) in the leaf tissue of *Calophyllum brasiliense*, under different levels of shading in a forest nursery.
Figura 2 – *Efeito do sombreamento na concentração de Ca e Mg (A e B) e na eficiência no uso interno de P e S (C e D) no tecido foliar de* ***Calophyllum brasiliense****, sob diferentes níveis de sombreamento, em viveiro florestal.*

the increase in production of photoassimilates that accumulate in the stem of plants (Siebeneichler et al., 2008), leading to an increase in the thickness and resistance of the stem. The best development in height at 70% shading characterizes this species as "functionally late" regarding growth. In the field, the presence of species that provide shade benefited *C. brasiliense*, which showed linear growth (Moraes et al., 2006). Valadão et al. (2014) and Reis et al. (2015) observed a similar behavior in the native Brazilian tree species *Physocalymma scaberrimum* Pohl and *Dilodendron bipinnatum* Radlk, respectively.

The highest leaf production at 70% shading may also have favored greater production of photoassimilates, as Silva et al. (2007) also observed, which contributed to greater growth in seedling diameter and height. The number of leaves at full sunlight and 30% shading similar to that of the treatment at 70% shading (they did not differ in any measurements – DAS) may indicate that *Calophyllum brasiliense* invested in the production of leaf biomass in an attempt to use the excess of light. However, this investment did not bring benefits regarding stem diameter and height, as the treatments at full sunlight and 30% shading showed the lowest averages, probably due to losses generated by the photoinhibition process (Dias and Marenco, 2006).

Physocalymma scaberrimum (Valadão et al., 2014) and *Copaifera langsdorffii* Desf. (Reis et al., 2016) showed similar results as those found in the present study, with the highest values of RDM, SDM, and

TDM under intermediate levels of light incidence. These species are probably very efficient in the use of light radiation to produce photoassimilates, which reflects in a higher accumulation of the total dry mass in seedlings that grow in environments that meet the ecological requirements of the species (Silva et al., 2007; Kylafis; Loreau, 2011).

Seedlings with the best H/SD and R/S ratios are also those that met the pattern of best allometric relationship in biomass distribution (Caione et al., 2012). The H/SD ratio is important because it is related to plant survival and growth in the field (Carneiro, 1995). We assumed that this ratio should range between 4 and 5 for *Calophyllum brasiliense* because H/SD has a strong influence on DQI. However, the highest TDM values recorded at 50 and 70% shading in the present study also contributed to seedlings reaching the best DQI in these environments. The seedlings with the highest DQI values are possibly the most vigorous and with chances of obtaining greater success in acclimatization and establishment processes when transported to the field. Certainly, the *C. brasiliense* seedlings that grew under intermediate shading, in particular at 70% shading, are less exposed to the processes of photoinhibition (Dias and Marenco, 2006). Therefore, these seedlings have better adjustments in the leaf chlorophyll content and better efficiency in light capitation (Sousa and Valio, 2003), which contributes to a higher efficiency in carbon accumulation (Lee and Graharm, 1986; Dias-Filho, 1997).

The low concentration of P observed in the leaves of *Calophyllum brasiliense* indicates high efficiency in the internal use (EIUN) of this nutrient, though plants required it in large amounts (Gliessman, 2005). The contrary occurred with N, which was the nutrient of highest concentration in leaves of *C. brasiliense*, and therefore, the EIUN for N was low. Bündchen et al. (2013) obtained the same result for other tree species. However, the plant can absorb and use more N as a strategy to improve the efficiency of the photosynthesis process (Hirose and Bazzaz, 1998).

The low concentration of P, Ca, Mg, and S suggests that these elements do not limit the growth of *Calophyllum brasiliense*, though they are essential for the development and mineral nutrition of plant in general (Malavolta, 1989). The decreasing concentration of P, Ca, Mg, and S and the more vigorous growth of seedlings with the increase of shading reveal high EIUN, instead of a deficiency or any nutritional dysfunction of *C. brasiliense*. Those nutrients also showed the highest EIUN in the tree species studied by Bündchen et al. (2013) in southern Brazil.

As recorded for other parameters, the high values of EIUN at 70% shading demonstrate that this light condition is suitable for the growth of *Calophyllum brasiliense* seedlings. Hence, *C. brasiliense* realizes its nutritional niche better under the canopy, which represents an ecophysiological advantage over other pioneer tree species (*r* strategy) that usually have low physiological performance under shading conditions, and even at intermediate luminosity levels (Popma and Bongers, 1988). The higher growth of seedlings at intermediate light conditions results from the proper functioning of their physiological system, as observed by Reis et al. (2015). This proper functioning contributes to the efficiency in the transportation and internal distribution of nutrients. In this case, the best environmental condition in which the plant grows, such is the case of *C. brasiliense*, should be understood as the one in which the logistics of nutrient transportation works to maximize biomass incorporation and distribution, resulting in more vigorous seedlings in these environments.

5. CONCLUSION

The ideal conditions to produce *Calophyllum brasiliense* are met in plant nurseries between 50 and 70% shading, which favors the vigor of the seedling and assures higher success in field planting. The low concentration of nutrients in the leaf tissue of *C. brasiliense* under intermediate light conditions suggests that, under these conditions, the species shows high efficiency in the internal use of nutrients instead of nutritional deficiency.

6. ACKNOWLEDGEMENTS

We thank the Research Foundation of Mato Grosso (FAPEMAT) for funding the present study (project 0738/2006), the Brazilian National Council for Scientific and Technological Development (CNPq) for the financial support to the plant nursery as part of the Project 575019/2008-5 coordinated by BH Marimon Jr., and the company Agro São Gabriel Ltda. for funding the irrigation system.

7. REFERENCES

Almeida LP, Alvarenga AA, Castro EM, Zanela SM, Vieira CV. Crescimento inicial de plantas de *Cryptocaria aschersoniana* Mez. submetidas a níveis de radiação solar. Ciência Rural. 2004;34(1):83-8.

Alvarenga AA, Castro EM, Lima-Junior EC, Magalhães MM. Effects of different light levels growth and photosynthesis of *Croton urucurana* Baill. in Southeastern Brazil. Revista Árvore. 2003;27(1):53-7.

Bündchen M, Boeger MRT, Reissmann CB, Silva SLCD. Status nutricional e eficiência no uso de nutrientes em espécies arbóreas da floresta subtropical no sul do Brasil. Scientia Forestalis. 2013;41(98):227-36.

Caione G, Lange A, Schoninger EL. Crescimento de mudas de *Schizolobium amazonicum* (Huber ex Ducke) em substrato fertilizado com nitrogênio, fósforo e potássio. Scientia Forestalis. 2012;40(94):213-21.

Carneiro JGA. Produção e controle de qualidade de mudas florestais. Curitiba: UFPR/FUPEF; 1995. 451p.

Carvalho PER. Espécies arbóreas brasileiras. Brasília: Embrapa Florestas; 2003. 1039p.

Chapin III FS. The mineral nutrition of wild plants. Annual Review of Ecology and Systematics. 1980;11(1):233-60.

Dias DP, Marenco RA. Photoinhibition of photosynthesis in *Minquartia guianensis* and *Swietenia macrophylla* inferred by monitoring the initial fluorescence. Photosynthetica.2006;44(2):235-40.

Dias-Filho MB. Physiological response of *Solanum crinitum* Lam. to contrasting light environments. Pesquisa Agropecuária Brasileira. 1997;32(8):789-96.

Dickson A, Leaf AL, Hosner JF. Quality appraisal of white spruce and white pine seedling stock in nurseries. Forest Chronicles. 1960;36(1):10-3.

Empresa Brasileira de Pesquisa Agropecuária - Embrapa. Manual de análises químicas de solos, plantas e fertilizantes. Brasília, D.F.: Embrapa Solos; 1999. 370p.

Gliessman SR. Agroecologia: processos ecológicos em agricultura sustentável. 3ª.ed. Porto Alegre: Universidade Federal do Rio Grande do Sul; 2005. 653p.

Hammer Ø, Harper DAT, Ryan PD. Past: paleontological statistics software package for education and data analysis. Palaeontologia Electronica. 2001;4(4):1-9.

Haridasan M. Nutritional adaptations of native plants of the cerrado biome in acid soils. Brazilian Journal of Plant Physiology. 2008;20(3):183-95.

Hirose T, Bazzaz FA. Trade-oû between light- and nitrogen-use eûciency in canopy photosynthesis. Annals of Botany. 1998;82(2):195-202.

Kylafis G, Loreau M. Niche construction in the light of niche theory. Ecology Letters. 2011;14(2):82-90.

Lee DW, Graham R. Leaf optical properties of rainforest sun and extreme shade plants. *American* Journal of *Botany*. 1986;73(8):1100-8.

Lima-Junior EC, Alvarenga A, Castro EM. Trocas gasosas, características das folhas e crescimento de plantas jovens de *Cupania vernalis* Camb. submetidas a diferentes níveis de sombreamento. Ciência Rural. 2005;35(5):1092-7.

Lopes SP, Schiavini I. Dinâmica da comunidade arbórea de mata de galeria da Estação Ecológica do Panga, Minas Gerais, Brasil. Acta Botanica Brasílica. 2007;21(2):249-61.

Lorenzi H. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas do Brasil. 5ª. ed. Nova Odessa: Plantarum; 2008. 368p.

Malavolta E. Avaliação do estado nutricional das plantas: princípios e aplicações. Piracicaba: Associação Brasileira para Pesquisa do Potássio e do Fosfato; 1989. 201p.

Marimon BS, Felfili JM, Marimon-Júnior BH, Franco AC, Fagg CW. Desenvolvimento inicial e partição de biomassa de Brosimum rubescens Taub. (Moraceae) sob diferentes níveis de sombreamento. Acta Botanica Brasilica. 2008;22(4):941-53.

Marimon BS, Felfili JM, Lima EDS, Duarte WMG, Marimon-Júnior BH. Environmental determinants for natural regeneration of gallery forest at the Cerrado/ Amazonia boundaries in Brazil. Acta Amazonica. 2010;40(1):107-18.

Marimon BS, Marimon-Junior BH, Feldpausch TR, Oliveira-Santos C, Mews HA, Lopez-Gonzalez G et al. Disequilibrium and hyperdynamic tree turnover at the forest–cerrado transition zone in southern Amazonia. Plant Ecology & Diversity. 2014;7(1):1-12.

Moraes LFD, Assumpção CL, Pereira TS. Plantio de espécies arbóreas nativas para a restauração ecológica na Reserva Biológica de Poço das Antas, Rio de Janeiro, Brasil. Rodriguésia. 2006;57(3):477-89.

Oliveira-Filho AT, Ratter JA. A study of the origin of central Brazilian forests by the analysis of plant species distribuition patterns. Edinburgh Journal of Botany. 1995;52(2):141-94.

Popma J, Bongers F. The effect of canopy gaps on growth and morphology of seedlings of rain forest species. Oecologia. 1988;75(4):625-32.

R Development Core Team. A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing; 2014.

Reis SM, Morandi PS, Oliveira B, Oliveira ED, Valadão MBX, Marimon BS et al. Influência do sombreamento no desenvolvimento inicial e eficiência no uso de nutrientes de *Dilodendron bipinnatum* Radkl (Sapindaceae). Scientia Forestalis. 2015;43(107):581-90.

Reis SM, Marimon-Júnior BH, Morandi PS, Oliveira-Santos C, Oliveira B, Marimon BS. Desenvolvimento inicial e qualidade de mudas de *Copaifera langsdorffii* Desf. sob diferentes níveis de sombreamento. Ciência Florestal. 2016;26(1):11-20.

Siebeneichler SC, Freitas GAD, Silva RRD, Adorian GC, Capellari D. Características morfofisiológicas em plantas de *Tabebuia heptaphyilla* (Vell.) Tol. em condições de luminosidade. Acta Amazonica. 2008;38(3):467-72.

Silva FAM, Assad ED, Evangelista BA. Caracterização climática do Bioma Cerrado. In: Sano SM, Almeida SP, Ribeiro JF, editores. Cerrado: Ecologia e Flora. Planaltina: Embrapa; 2008. p.69-88.

Silva RR, Freitas GD, Siebeneichler SC, Mata JD, Chagas JR. Desenvolvimento inicial de plântulas de *Theobroma grandiflorum* (Willd. ex Spreng.) Schum. sob influência de sombreamento. Acta Amazonica. 2007;37(3):365-70.

Soares-Filho B, Rajão R, Macedo M, Carneiro A, Costa W, Coe M et al. Cracking Brazil’s Forest Code. Science. 2014;344:363-4.

Sousa RP, Válio IFM. Leaf optical properties as affected by shade in saplings of six tropical tree species differing in successional status. Brazilian Journal of Plant Physiology. 2003;15(1):49-54.

Swaine MD, Whitmore TC. On the difinition of ecological species groups in tropical rain forests. Vegetatio. 1988;75(1):81-6.

Taiz L, Zeiger E. Fisiologia vegetal. 4ª.ed. Porto Alegre: Artmed; 2009. 820p.

Valadão MBX, Marimon-Junior BH, Morandi PS, Reis SM, Oliveira BD, Oliveira EAD et al. Initial development and biomass partitioning of Physocalymma scaberrimum Pohl (Lythraceae) under different shading levels. Scientia Forestalis. 2014;42(101):129-39.

Vitousek P. Nutrient cycling and nutrient use efficiency. The American Naturalist. 1982;119(4):553-72.

Zar JH. Biostatistical analysis. New Jersey: Prentice Hall; 2010. 944p.