

Shading improves initial growth and quality of *Parkia multijuga* Benth. seedlings**Noemi Vianna Martins Leão^{1*}, Elizabeth Santos Cordeiro Shimizu¹, Sérgio Heitor Sousa Felipe²**¹Embrapa Amazônia Oriental, Laboratório de Sementes Florestais, Belém, PA, Brazil²Universidade Federal de Viçosa, Laboratório de Cultura de Tecidos/BIOAGRO, Viçosa, MG, Brazil***Corresponding author: noemi.leao@embrapa.br****Abstract**

During the production of forest seedlings, light quantity can indicate the degree of tolerance of tree species to shading conditions and provide information to obtain seedlings with a higher quality standard. The objective of this study was to evaluate the effect of different levels of shading on the emergence and the quality standard of *Parkia multijuga* Benth. seedling, a timber species that can be used in landscaping and restoration of degraded areas. The experimental design was completely randomized, consisting of three treatments: full sunlight (control; 2050 $\mu\text{mol m}^{-2} \text{s}^{-2}$), 50 (1025 $\mu\text{mol m}^{-2} \text{s}^{-2}$), and 70% (615 $\mu\text{mol m}^{-2} \text{s}^{-2}$) shading obtained with black polyethylene screens. The results showed that the applied treatments did not significantly influence the emergence percentage. However, under unshaded conditions (i.e., full sunlight), the seeds displayed a higher velocity index and a shorter mean time of seedling emergence. On the other hand, the different levels of shading (50 and 70%) improved the growth performance (e.g., higher shoot height, collar diameter, number of leaves) and quality (e.g., higher Dickson Quality Index (DQI)) of *P. multijuga* seedlings. Furthermore, seedlings under 50 and 70% shading displayed a significant increase in the total biomass compared to those exposed to the full sunlight condition (243 and 195%, respectively). In addition, the DQI was higher in plants grown at 50 and 70% shading in comparison with the full sunlight treatment (145 and 85%, respectively). The shading level of 50% is recommended for the production of *P. multijuga* seedlings with the highest quality standard in the nursery beds in Brazilian Amazon.

Keywords: Brazilian Amazon; Forest species; Light quantity; Reforestation; Seedling quality.**Abbreviations:** DML_Dry mass of the leaves; DMR_Dry mass of the root; DMS_Dry mass of the stem; DMSH/DMR_Ratio of the dry mass of the shoot and root; DMSH_Dry mass of the shoot; DQI_Dickson quality index; EMT_Emergence mean time; EVI_Emergence velocity index; H/ \emptyset _Ratio of the shoot height and collar diameter; H_Height; NL_Number of leaves; \emptyset _Collar diameter; RL_Root length; TDM_Total dry mass.**Introduction**

The recovery or restoration of deforested areas requires high-quality seedlings of enough quantity to adapt to adverse conditions in the field. However, for many forest species in the Amazon forest, there is not sufficient information on seedling production technologies (Brito et al., 2017). Due to the great diversity of tree species present in the Amazon region, it is essential that research can be carried out on the greatest number of species, defining the best methods to produce seedlings that guarantee a higher quality standard (Leão et al., 2015).

There is a high demand for seedling production of native forest species for reforestation purposes in Brazilian Amazon (Souza et al., 2018). Among the species that present a high potential for use in reforestation programs *Parkia multijuga* Benth. is a species with high economic value being used in the furniture manufacturing (Carvalho, 2008). This species belongs to the Fabaceae family, popularly known as *fava-arara-tucupi*, *faveira*, *paricá-de-terra-firme*, *faveira-benguê*, and *pinho-cuiabano* in Brazil. It is typical of the Amazon Biome and occurs in the *terra firme* and *várzea alta* forests.

In addition, this species can reach 40 m in height, being an important species for the recovery of degraded areas due to its rapid growth (Carvalho, 2008).

The production of seedlings in an elevated quantity and with a higher quality standard is necessary to guarantee success in the various reforestation programs (Dantas et al., 2018). On the other hand, this production must be achieved in a practical, rapid, and easy manner (Fonseca et al., 2002). Among the easy-handling factors that may directly influence seedlings production, light quantity is highlighted, being determinant for photosynthesis, growth, development, and partitioning of assimilates among the plant organs (Marana et al., 2015). In this context, several studies have applied the Dickson Quality Index (DQI) (Dickson et al., 1960) to determine the quality standard of tree species seedlings, since this index ponders several important parameters such as height, collar diameter, and shoot and root biomass (Fonseca et al., 2002). In general, the higher index equals to the higher quality of the seedling (Gomes, 2002).

Studies approaching different light quantity levels are capable of identifying the tolerance degree of certain species to specific shading conditions during the production phase of seedlings (Campos and Uchida, 2002). For this reason, this type of research is extremely important for the development of forest activity and for conservation and reforestation programs (Albuquerque et al., 2015). In addition, this knowledge contributes to the development of seedling production systems aimed at commercialization (Lone et al., 2009).

For the species *P. multijuga*, studies involving seedling production are scarce. Therefore, understanding the effects of different light quantity levels on seedling production of this species will disclose information about the plasticity of the species and the best level of shading to produce vigorous seedlings with higher quality in shorter time during the nursery phase.

Considering the necessity to understand the light quantity requirements of each plant species in the process of seedling production (Queiroz and Firmino, 2014), the present research aimed to evaluate the effects of different shading levels in the emergence, initial growth, and quality standard of *P. multijuga* seedlings.

Results and Discussion

Full sunlight increases emergency uniformity of *P. multijuga*

The *P. multijuga* seeds had a moisture content of 9.8% and an average of 206 seeds per kilogram. Shading levels did not influence the emergence percentage, but the seeds exposed to full sunlight showed a higher EVI and a lower EMT (Table 2). This response represented by the EVI and EMT may be directly related to the successional characteristic of the species, since *P. multijuga* is characterized as an initial secondary species (Carvalho et al., 2009).

The species belonging to this successional ecological group develop in clear or in some cases, shaded understories (Santos et al., 2004). The greater the EVI, the greater the emergency uniformity, which leads to obtaining seedlings in a shorter time. In the current study, we believe that full sunlight treatment provided a higher metabolic activity in seeds driven by the arrival of more energy to the seeds (i.e., 2050 $\mu\text{mol m}^2 \text{s}^{-2}$), which in turn, led to the best performance in EVI (i.e., higher index) and TME (i.e., lower index) compared to 50 and 70% shading treatments.

Shading improves growth performance in *P. multijuga*

The *P. multijuga* seedlings presented growth variations, with significant differences ($p \leq 0.05$) for all traits analyzed, except for root length (Table 3). For the shoot height (H) variable, the seedlings under full sunlight conditions were smaller in length, and both 50 and 70% shading levels promoted more than twice the gain in height compared to seedlings exposed to full sunlight (Table 3). There was no statistical difference between the 50 and 70% shading levels, but both conditions differed from the full sunlight treatment. Plants subjected to long periods of high irradiance can present, resulting to lower photosynthetic efficiency and biomass incorporation

(Kitao et al., 2000). These results observed for the shoot height variable are similar to those obtained by Queiroz and Firmino (2014), who observed higher heights in the *Dipteryx alata* plants grown under shading, when compared to full sunlight conditions, where there were no significant differences between the shading levels evaluated. For *Dalbergia nigra* (Pacheco et al., 2013) and *Azadirachta indica* (Azevedo et al., 2015), bigger seedlings were also observed, when they were exposed to increasing shading levels.

The collar diameter of the seedlings under full sunlight did not differ among seedlings under 50% shading; however, this variable differed for the seedlings under 70% shading, which presented larger diameter. No significant difference was observed, comparing the seedlings under 50 with those under 70% shading (Table 3).

This difference observed for the collar diameter of full sunlight seedlings and those under 70% shading is similar to those observed for *Dalbergia nigra* seedlings (Pacheco et al., 2013). However, for other species such as *Pseudopiptadenia psilostachya* (Fonseca et al., 2006) and *Bertholletia excelsa* (Albuquerque et al., 2015), there was an increase in their diameter at shading levels of around 50%, followed by a decrease in the collar diameter, when the shading level was increased above 50%. The combined increase in the collar diameter and shoot height may indicate that photosynthesis and respiration are in a favorable balance (Dutra et al., 2011).

The number of leaves was higher for the seedlings grown under 50 and 70% shading, with no significant difference between these conditions. Nevertheless, both 50 and 70% shading levels differed from the seedlings under full sunlight, which presented the lowest values (Table 3). Forest species such as *Dipteryx alata* (Queiroz and Firmino, 2014) and *Syagrus coronata* (Carvalho et al., 2006) have been reported as producing a greater number of leaves under shaded environments, compared to full sunlight conditions, corroborating with the results presented here. However, other species such as *Bertholletia excelsa* (Albuquerque et al., 2015) and *Pseudopiptadenia psilostachya* (Fonseca et al., 2006) did not show differences in number of leaves, comparing shading and full sunlight conditions, while other species such as *Azadirachta indica* (Azevedo et al., 2015) and *Caesalpinia echinata* (Aguar et al., 2011) presented lower numbers of leaves under shading environments.

Plants with a well-developed shoot improve the capture of photosynthetically active radiation in order to maintain a more vigorous growth (Castro-Henrique et al., 2011). In this context, shading induces plant species to develop strategies such as greater leaf surface for the maximum absorption of light rays (Almeida et al., 2005). Interestingly, there are species with greater plasticity in adapting to these conditions than others.

For the root length variable, the seedlings under 0%, 50%, and 70% shading did not differ significantly (Table 3). These results are supported by those observed for *Dipteryx alata* (Queiroz and Firmino, 2014). A greater root growth is essential for an increased water uptake in different soil strata.

Table 1. Maximum temperature (MT), average temperature (AT), minimum temperature (MT), relative humidity (RH) and sunshine during the experimental period.

Period (month/ year)	MT (°C)	AT (°C)	MT (°C)	RH (%)	Sunshine (h)
Nov./ 2009	33.8	28.0	23.4	74.0	240.8
Dec./ 2009	32.9	27.4	24.0	84.0	148.0
Jan./ 2010	32.1	27.0	23.8	86.4	163.0
Feb./ 2010	32.4	27.3	24.2	84.6	152.7
Mar./ 2010	32.4	27.6	24.3	83.7	197.6
Apr./ 2010	32.2	27.1	24.1	87.3	123.8
May/ 2010	32.7	27.7	24.4	84.7	191.9
Jun./2010	32.5	27.3	23.5	80.6	230.4

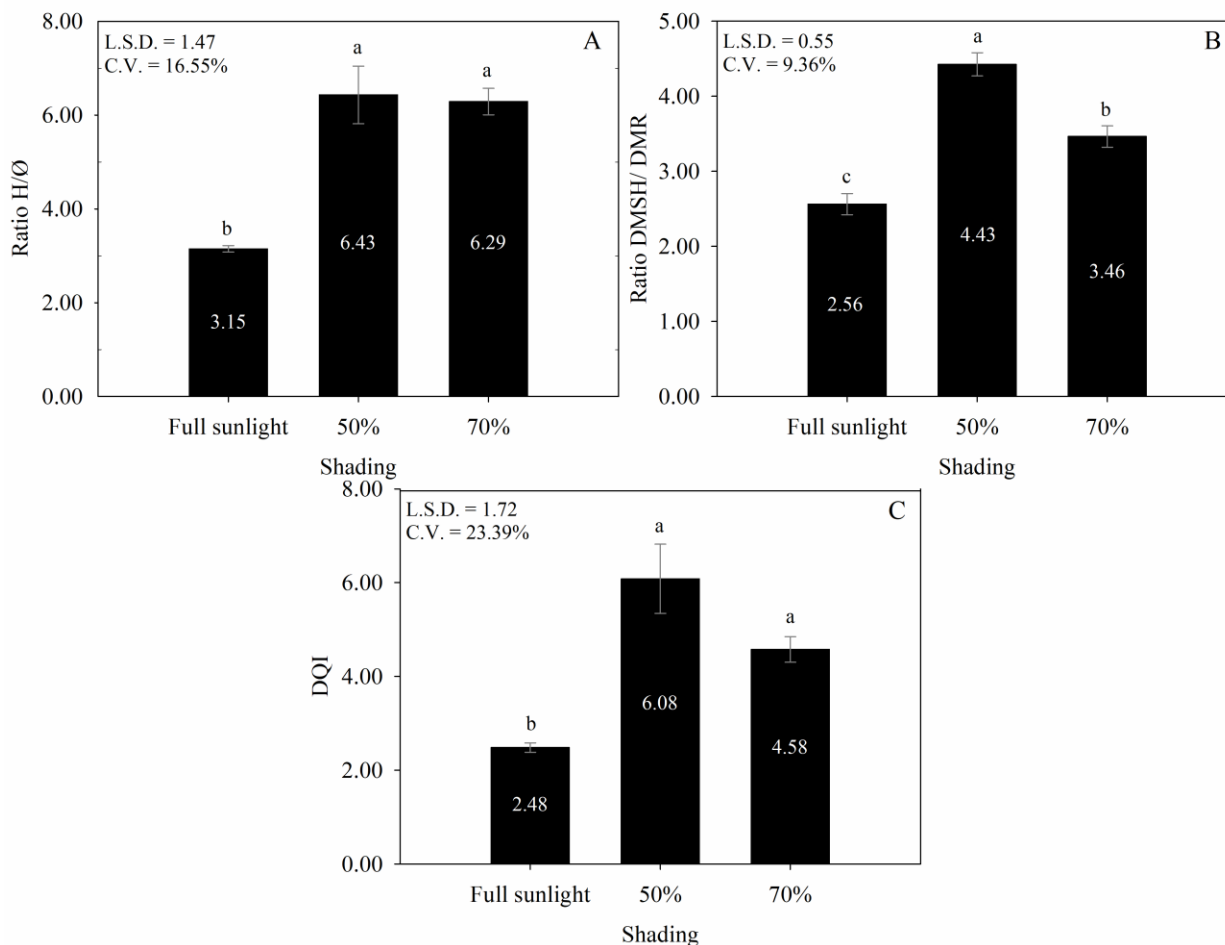


Fig 1. Quality indexes of six-month-old *Parkia multijuga* seedlings grown in full sunlight (control), 50 and 70% shading. A - ratio of the shoot height and collar diameter (H/ Ø), B - ratio of the dry mass of the shoot, and root (DMSH /DMR), and C - Dickson Quality Index (DQI). Means followed by the same letter do not differ at 5% Tukey's test. L.S.D. = less significant difference and C.V. = coefficient of variation. The bars represent the standard error.

Table 2. Emergence percentage (EP), emergence velocity index (EVI) and emergence mean time (EMT) of *Parkia multijuga* seeds under full sunlight (control), 50 and 70% shading.

Shading ¹	EP (%)	EVI	EMT
Full sunlight (control)	89 a	1.66 a	13.56 b
50%	78 a	1.37 b	14.75 a
70%	88 a	1.44 ba	15.19 a
Mean ²	85	1.49	14.50
L.S.D.	14.36	0.27	1.06
C.V. (%)	8.56	9.19	3.69

¹Means followed by the same letter in the columns do not differ at 5% Tukey's test. ²Mean = General Mean, L.S.D. = less significant difference and C.V. = coefficient of variation.

Table 3. Characteristics of six-month-old *Parkia multijuga* seedlings grown in full sunlight (control), 50 and 70% shading.

Characteristics ¹	Shading ²			Mean ³	L.S.D.	C.V. (%)
	Full sunlight (control)	50%	70%			
H (cm)	27.60 b	56.84 a	63.88 a	49.44	15.12	18.11
Ø (mm)	8.77 b	9.61 ba	10.69 a	9.69	1.19	7.30
NL (unid.)	2.92 b	8.55 a	7.70 a	6.39	1.17	10.88
RL (cm)	29.66 a	38.23 a	37.17 a	35.02	11.84	20.03
DML (g)	2.67 c	18.68 a	14.64 b	12.00	3.69	18.25
DMS (g)	7.62 b	20.92 a	17.93 a	15.49	4.64	17.77
DMSH (g)	10.30 b	39.60 a	32.56 a	27.49	8.13	17.53
DMR (g)	4.00 b	9.46 a	9.56 a	7.67	2.64	20.44
TDM (g)	14.29 b	49.06 a	42.12 a	35.15	10.67	18.00

¹Shoot height (H), collar diameter (Ø), number of leaves (NL), root length (RL), dry mass of the leaves (DML), dry mass of the stem (DMS), dry mass of the shoot (DMSH), dry mass of the root (DMR) and total dry mass (TDM). ²Means followed by the same letter in the lines do not differ at 5% Tukey's test. ³Mean = General Mean, L.S.D. = less significant difference and C.V. = coefficient of variation.

Analysis of the dry mass of the leaves showed that the lowest accumulation of leaf biomass was occurred under the full sunlight treatment, while biomass accumulation was increased under 50% and reduced under 70% shading (Table 3).

For the dry mass of the stem, dry mass of the shoot, dry mass of the root, and total dry mass, the response pattern was similar among these variables (Table 3). The lowest accumulation of biomass was observed in the seedlings under full sunlight conditions. In contrast, seedlings under 50 and 70% shading levels presented the largest accumulations of biomass, with these shading conditions not differing from each other. Results such as these indicate the needs during the initial development of the species under shading conditions to obtain seedlings with higher quality for field planting (Chaves and Paiva, 2004).

Similar results were observed for other species such as *Dipteryx alata* (Queiroz and Firmino, 2014) and *Caesalpinia ferrea* (Lenhard et al., 2013) with a higher accumulation of biomass in plants under shading conditions. The different levels of light can cause morphological and physiological changes in the plant. The degree of adaptation is induced by the genetic characteristics of each species and the environment (Scalon et al., 2003). In addition, each species presents specific light requirements for its development (Azevedo et al., 2015).

Shading increases the quality standard of *P. multijuga* seedlings

The ratio between shoot height and collar diameter was lower for the seedlings subjected to full sunlight compared to those grown under 50 and 70% shading (Fig 1A). Similar results have been observed for several forest species such as *Caesalpinia echinata* (Aguar et al., 2011), *Dalbergia nigra* and *Chorisia speciosa* (Pacheco et al., 2013), and *Azadirachta indica* (Azevedo et al., 2015), for which the highest ratios verified in seedlings grown under shading levels. Plants with lower ratios show a better balance between their parts and consequently better seedling quality (Silva et al., 2007). However, this parameter has a disadvantage, since it does not consider the root system of the seedlings (Carneiro, 1995).

Regarding the ratio between DMSH and DMR, the seedlings grown under 50% shading were superior to those under 70% and full sunlight conditions (Fig 1B). These results support

partially the observation on *Caesalpinia echinata* plants, in which a positive correlation was verified between shading levels and this ratio (Aguar et al., 2011). Similarly, *Jacaranda copaia* plants exhibited the highest values of this ratio under 50 and 70% shading (Campos and Uchida, 2002). In response to low light, plants accumulate less dry mass and retained larger amounts of photoassimilates in the shoot and smaller amounts in the root (Carvalho, 1996).

The DQI was higher for the 50% shading treatment; however, there was no difference between the 50 and 70% shading levels. On the other hand, both shading treatments differed from the full sunlight treatment, which presented the lowest value of this index (Fig 1C). Unlike our results, *Sclelorobium paniculatum* plants did not present differences when exposed to full sunlight and shading environments (Freitas et al., 2012). Our results suggest divergence from the observations on *Azadirachta indica* (Azevedo et al., 2015) and *Erythrina velutina* species (Santos and Coelho, 2013), which presented high quality when grown under full sunlight conditions. Nonetheless, similarly to our findings, *Senna macranthera* (Chaves and Paiva, 2004) and *Physocalymma scaberrimum* (Valadão et al., 2014) seedlings presented higher indexes under shading. The higher DQI observed for *P. multijuga* seedlings grown under 50% shading may reflect in a greater adaptation of these plants to adverse field conditions. As a result, future operational costs might be reduced in reforestation or commercial planting projects such as replanting seedlings in the field.

Materials and methods

Location and climate of the study area

This research was conducted from November 2009 to June 2010, in the nursery beds of the Forest Seed Laboratory (LASF) of Embrapa Eastern Amazon, Belém, Pará state, Brazil (01° 28' S, 48° 27' W). The climate in the region is classified, according to Koeppen's classification, as Af with an average annual rainfall varying from 3,000 to 4,000 mm and an average temperature of 26.4 °C, unstable air, and 84% average air humidity (Bastos et al., 2002; Alvares et al., 2013).

Plant material, number of seeds per kilogram and moisture content of seeds

P. multijuga seeds were purchased from the Eletrobras Eletronorte seed laboratory, located in the municipality of

Tucuruí, Pará state, Brazil. The mass of one thousand seeds was estimated with the separation of eight samples with 100 seeds each weighed in a scale, with a precision of 0.0001 g. In order to determine the moisture content of the seeds, two seeds divided in half by an aluminum capsule were used, consisting of four replicates, which were kept in an oven at 105 ± 3 °C for 24 hours (Brasil, 2009).

Conduction of the experiment and experimental design

The seeds were submitted to integument dormancy breaking through manual mechanical scarification by sandpaper (No. 120), in the opposite region to the seed hilum, according to Shimizu et al. (2011). Subsequently, the seeds were sown in black polyethylene bags (15 × 25 cm) with substrate made from a mixture of surface forest soil, tanned bovine manure, and tanned sawdust at a ratio of 3:1:2, respectively (pH = 7.0; N = 0.09%; P = 609 mg dm⁻³; K = 1273 mg dm⁻³; Na = 367 mg dm⁻³; Ca = 4.2 Cmol_c dm⁻³; Ca+Mg = 6.4 Cmol_c dm⁻³; Al = 0.0 Cmol_c dm⁻³).

The bags were placed in three shading levels: full sunlight (control treatment), 50 and 70% shading (or 2050, 1025 and 615 μmol m⁻² s⁻², respectively, measured at 12 a.m., local time, on a cloudless day). The mean air temperature and relative humidity during the experimental period were measured in an Agrometeorological Station of Embrapa Eastern Amazon, Belém, Pará state, Brazil (Table 1).

The shading was provided by black polyethylene screens (sombrite type), fixed in a wooden frame on the upper and side parts of the beds. The plants were irrigated daily when necessary. After six months, *P. multijuga* seedlings samplings and measurements were performed.

The experimental design was completely randomized (CRD), and the emergence test consisted of four replicates of 25 seeds per treatment. For the evaluation of the effect of light quantity on seedling production, five replications of five plants per treatment were used.

Traits measured

The emergence percentage was calculated by the ratio (number of seedlings emerged / total number of seeds) × 100; the emergence velocity index (EVI) and the emergence mean time (EMT). It was calculated according to the formula of Maguire (1962) and Edwards (1934), respectively.

A millimeter ruler was used to measure shoot and root length, and a caliper was used to measure the collar diameter. For the drying of the plant material (leaf, stem, and root), an oven with forced air circulation at 65 °C until mass stabilization was used (Maldaner et al., 2009). Weight measures of the plant organs were obtained with a precision scale.

The shoot height (H) was determined by the measuring from the collar region of the seedling to the apical bud. The collar diameter (Ø) was measured on the stem at the substrate level. The number of leaves (NL) was performed by counting all the leaves in the plant. The root length (RL) was measured from the region below the collar to the apical bud of the longest root. The dry mass of the leaves (DML), stem (DMS), and root (DMR) were obtained separately and through the sum of the DML and DMS. The dry mass of the

shoot (DMSH) was obtained, and then sum of DML, DMS, and DMR, the total dry mass (TDM) were calculated.

For the seedling quality indexes, the following parameter were evaluated: the ratio of the shoot height and collar diameter (H/ Ø); the ratio of the dry mass of the shoot and root (DMSH /DMR); and Dickson Quality Index (DQI) (DQI = TDM/(H/Ø + DMSH / DMR)) (Dickson et al., 1960).

Statistical analysis

All variables were analyzed statistically. The data were initially analyzed by ANOVA, when significance observed, the Tukey's test was performed at a 5% probability level ($P \leq 0.05$). All analyses were performed with the aid of the SISVAR statistical software.

Conclusion

Our results show that full sunlight treatment has increased the uniformity of *P. multijuga* seedling emergence. On the other hand, these seedlings were more efficient on the use of their photoassimilates (i.e., higher growth and better biomass partition between aerial part and root system) when cultivated under 50 and 70% shading. Most importantly, the 50% shading is the most suitable condition for the production of *P. multijuga* seedlings with the highest quality standard in the nursery beds in Brazilian Amazon.

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