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MUSEU PARAENSE EMÍLIO GOELDI- MPEG
MESTRADO EM CIÊNCIAS BIOLÓGICAS

MONYCK JEANE DOS SANTOS LOPES

RESPOSTAS MORFOFISIOLÓGICAS E A ATIVIDADE CAMBIAL EM MUDAS DE *Parkia gigantocarpa* Ducke E *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby SOB SOMBREAMENTO

BELÉM – PA
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Orientador: Dr. João Ubiratan Moreira dos Santos
Co-orientador: Ph.D Moacyr Bernardino Dias-Filho
Co-orientador: Dr. Marco Antônio Menezes Neto

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LISTA DE ABREVIATURAS

H – Altura

D – Diâmetro

TDM – Matéria seca total

LDM – Matéria seca foliar

SDM – Matéria seca caulinar

RDM – Matéria seca radicular

ADM – Matéria seca da parte aérea

IQD (DQI) – Índice de qualidade de Dickson

SLA – Área foliar específica

gs – Condutância estomática

E – Transpiração

A – Fotossíntese

X – xilema

P – floema

CA – Atividade cambial

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RESUMO

Variações na intensidade de luz são responsáveis por importantes alterações morfofisiológicas nas plantas, as quais afetam a qualidade das mudas. Por isso, este estudo objetiva avaliar a influencia do sombreamento na atividade cambial e, consequentemente, nas características morfofisiológicas de mudas de *Parkia gigantocarpa* Ducke (faveira-atanã) e *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby (paricá). O experimento foi realizado em viveiro da Embrapa Amazônia Oriental, em Belém, PA (01º28'40"S, 48º26'59"W). Vinte dias após a semeadura, mudas de *P. gigantocarpa* e *S. parahyba* foram distribuídas nas seguintes intensidades de sombreamento: pleno sol, baixa, média e alta (0%, 23%, 67% e 73% de sombreamento, ou 2000, 1540, 660 e 540 µmol.m^{-2}.s^{-1}, respectivamente, mensurados as 11h, horário local, em um dia sem nuvens) obtidas com telas de polietileno (sombrite), permanecendo 60 dias sob esses níveis de interceptação da luz solar. Os parâmetros medidos foram diâmetro do caule (D), altura da planta (H), produção de biomassa da parte aérea e das raízes, índice SPAD, condutância estomática (*gs*), transpiração (*T*), fotossíntese (*A*) e a atividade cambial da secção transversal do caule. Foram calculadas a H/D, a área foliar específica (SLA), a alocação de biomassa e o índice de qualidade de Dickson (DQI). O índice SPAD foi maior a pleno sol em ambas as espécies, também sendo maior sob a alta intensidade de sombreamento em *P. gigantocarpa*. Os maiores valores de produção de biomassa, *gs, E, A* e DQI foram encontrados a pleno sol, em *P. gigantocarpa,* e ao baixo sombreamento, em *S. parahyba*. A SLA em *P. gigantocarpa* aumentou com o incremento do sombreamento, enquanto que a alocação de carbono não diferiu dentre as intensidades de sombreamento. Em *S. parahyba* a SLA não sofreu efeito das variações de luz, mas o maior acúmulo de carbono nas folhas ocorreu com o aumento do sombreamento. Para ambas as espécies, a atividade cambial tendeu a diminuir sob maior intensidade de sombreamento. Concluiu-se que os parâmetros morfofisiológicos e a atividade cambial atuam em conjunto, explicando o crescimento radial e a qualidade das mudas, a qual foi otimizada a pleno sol, em *P. gigantocarpa*, e sob baixa intensidade de sombreamento, em *S. parahyba*.

Palavras-chave: faveira-atanã, paricá, produção de biomassa, xilema, fotossíntese, produção de mudas

ABSTRACT

Variations in light intensity are responsible for important morphophysiological changes in plants, affecting seedlings quality. This study aims to evaluate the influence of shade on the cambial activity and morphophysiological characteristics in seedlings of *Parkia gigantocarpa* Ducke and *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby. The experiment was conducted in the nursery seedling production unit of Embrapa Amazônia Oriental (01º 28'40"S, 48º26'59"W) in Belém, PA. Twenty days after sowing, seedlings of *P. gigantocarpa* and *S. parahyba*, grown in pots, were allocated to the following light environments: full sun, low, medium and high shade intensity (respectively, respectively, 0%, 23%, 67% and 73% of shade, or 2000, 1540, 660 and 540µmol.m^{-2}.s^{-1}, at canopy height, measured at 11am, local time, on a cloudless day) obtained with polyethylene screens, remaining for 60 days under these light levels. The parameters measured were stem diameter (D), plant height (H), biomass production of shoots and roots, SPAD index, stomatal conductance (*g*), transpiration (*E*) and photosynthesis (*A*). It was also measured the cambial activity of the cross section of the stem. We calculated H/D, specific leaf area (SLA), biomass allocation and the Dickson quality index (DQI). The SPAD index was higher under full sun in both species and also under high shade intensity in *P. gigantocarpa*. The highest values of biomass production, *gs, E, A* and DQI were measured under full sun, in *P. gigantocarpa*, and at low shade intensity, in *S. parahyba*. SLA in *P. gigantocarpa* increased with the increase in shade intensity, while carbon allocation did not differ among shade intensities. SLA in *S. parahyba* did not differ among treatments and carbon allocated to leaves increased with increasing shade. For both species, the cambial activity tended to decrease under the highest shade intensity. It was concluded that the cambial activity and morphophysiological parameters act together, explaining the radial growth and seedling quality, which was optimized under full sun, in *P. gigantocarpa*, and under low shade intensity in *S. parahyba*.

Keywords: faveira-atanã, paricá, biomass production, xylem, photosynthesis, seedling production

CONTEXTUALIZAÇÃO

As variações na intensidade de luz são responsáveis por importantes alterações morfofisiológicas nas plantas, afetando a fotossíntese, a produção de biomassa, o transporte de fotoassimilados e a relação fonte e dreno (VALLADARES & NIINEMETS, 2008; GOH *et al*., 2012). No entanto, todas as plantas possuem algum grau de plasticidade adaptativa, ou seja, são capazes de, em maior ou menor escala, modificarem seu comportamento morfofisiológico e anatômico a fim de usar mais eficientemente a luz disponível no ambiente (SEMCHENKO *et al*., 2012; HOUTER & POUNS, 2012).

Diversos autores afirmam que mudas florestais modificam suas características morfofisiológicas quando cultivadas sob déficit luminoso (e.g. AGUIAR *et al.*, 2011; DUTRA *et al.*, 2012; PIEREZAN *et al.*, 2012). De acordo com esses autores, dentre muitos parâmetros avaliados, o diâmetro do caule é comumente medido; pois, além de ser um dos parâmetros de maior plasticidade, o caule é o dreno preferencial na fase de desenvolvimento vegetativo, na qual as mudas se encontram. Isso por que é o responsável pela sustentação da planta, condução dos fotoassimilados, e, é essencial para a adaptação da muda em campo, sendo também importante à indústria madeireira (DOWNES *et al*.,2009; SPECK & BURGERT, 2011).

A variação do diâmetro do caule em resposta a luz é uma forma de adaptação ambiental que ocorre em razão da atividade cambial, a qual é estimulada por carboidratos, produzidos na fotossíntese, e por hormônios (TERRAZAS *et al*., 2011; DAYAN *et al*., 2012). De acordo com Dejardin *et al*. (2010), o aumento da atividade cambial eleva a produção de xilema, principal componente da madeira, aumentando o crescimento radial, ou seja, o diâmetro caulinar. No entanto essa atividade pode ser influenciada por fatores ambientais, como a luz, e por fatores intrínsecos à planta, como genética e fisiologia (RISOPATRON *et al*., 2010; TERRAZAS *et al*., 2011). Uma vez que essa atividade é afetada, hipotetiza-se aqui que a qualidade da muda também será influenciada.

Portanto, é primordial conhecer os requerimentos de luz das espécies florestais arbóreas, a fim de aperfeiçoar a produção de mudas a baixo custo e com qualidade morfofisiológica elevada, visando a atender programas de reflorestamento (NAKAZONO *et al*. 2001; NERY *et al.*, 2011). Dentre essas espécies, com aptidão ao reflorestamento e na formação de sistemas silvipastoris na Amazônia, estão as Leguminosae arbóreas, como *Parkia gigantocarpa* Ducke (faveira-atanã) e *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby (paricá), sendo, ambas as espécies de crescimento acelerado (BRIENZA JUNIOR *et al.*, 2008).

S. parahyba, pertence à subfamília Caesalpinioideae, é uma espécie pioneira amazônica, arbórea de mata primária e secundária, encontrada da terra firme a várzea alta, de crescimento excessivamente rápido (DUCKE, 1949). *P. gigantocarpa*, pertence à subfamília Mimosoideae, é uma espécie amazônica, arbórea e que habita terra firme em solos arenosos (LOUREIRO *et al*., 1977) e argilosos (DIAZ-BARDALES, 2001). Ambas as espécies são consideradas intolerantes a sombra (GOMES *et al*, 2010), sendo indicadas para plantios sob diferentes condições ambientais (BRIENZA JUNIOR *et al*., 2008).

Pouco se conhece sobre as espécies arbóreas amazônicas, sobretudo a *P. gigantocarpa.* Dessa forma, visando a ampliar o conhecimento anatômico e morfofisiológico das espécies arbóreas amazônicas, e, partindo da hipótese que o sombreamento influencia a atividade cambial e o desenvolvimento de mudas de espécies florestais, o presente estudo propõe avaliar a influência do sombreamento na atividade cambial e nas características morfofisiológicas de mudas de *P. gigantocarpa* (faveira-atanã) e *S. parahyba* Barneby (paricá), visando à produção de mudas aptas ao campo e com ótima qualidade morfofisiológica. Para alcançar esse objetivo, a pesquisa foi divida em duas partes (artigos):

1. Morphophysiological responses to shade in seedlings of *Parkia gigantocarpa* Ducke **and** *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby [**Respostas morfofisiológicas de mudas de** *Parkia gigantocarpa* Ducke **e** *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby **ao sombreamento**]

Nesse artigo discute-se o comportamento morfofisiológico das mudas de *P. gigantocarpa* e *S. parahyba* sob diferentes intensidades de luz.

2. Morphophysiological behavior and cambial activity in seedlings of two Amazonian tree species under shade [**Comportamento morfofisiológico e atividade cambial em mudas de duas espécies arbóreas amazônicas sob sombreamento**]

Nesse artigo avalia-se a influência do sombreamento no desenvolvimento e na atividade cambial em mudas de *P. gigantocarpa* e *S. parahyba*.

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2. Morphophysiological responses to shade in seedlings of *Parkia gigantocarpa* Ducke and *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby

2.1 ABSTRACT

Variations in light intensity are responsible for important morphophysiological changes in plants. The present study aims to evaluate the morphophysiological responses to shade in seedling of the Amazonian tree species *Parkia gigantocarpa* Ducke and *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby. An experiment was conducted in Belém, PA (01º28'40"S, 48º26'59"W). Twenty days after sowing, seedlings of *P. gigantocarpa* and *S. parahyba*, grown in pots, were allocated to the following light environments (treatments): full sun, low, medium and high shade intensity (respectively, 0%, 23%, 67% and 73% of shade, or 2000, 1540, 660 and 540μmol.m^{-2}.s^{-1}, at canopy height, measured at 11am, local time, on a cloudless day) obtained with polyethylene screens in a greenhouse. Eighty days after sowing, we measured the SPAD index, stomatal conductance (gs), transpiration (E), photosynthesis (A) and biomass production. We also calculated the specific leaf area (SLA) and carbon allocation. The highest values of *gs, E, A* and biomass production were found under full sun, in *P. gigantocarpa*, and at low shade intensity, in *S. parahyba*. The SPAD index was higher under full sun in both species and also under high shade intensity in *P. gigantocarpa*. In *P. gigantocarpa*, SLA increased with the increase in shade intensity, while carbon allocation did not differ among treatments. In *S. parahyba*, SLA did not differ among treatments and carbon allocated to leaves increased with increasing shade. *P. gigantocarpa* seedlings developed best under full sun, while *S. parahyba* seedlings performed better under low shade intensity.

Keywords: SPAD index, specific leaf area, photosynthesis.

Respostas morfofisiológicas em mudas de *Parkia gigantocarpa* Ducke **e** *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby **sob sombreamento**

2.2 Resumo

As variações na intensidade de luz são responsáveis por importantes alterações morfofisiológicas nas plantas. O presente estudo objetiva avaliar as respostas morfofisiológicas de mudas arbóreas amazônicas de *Parkia gigantocarpa* Ducke (faveira-atanã) e *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby (paricá) cultivadas sob sombreamento. O experimento foi conduzido em Belém, PA (01º28'40"S, 48º26'59"W). Vinte dias após a semeadura, mudas de *P. gigantocarpa* e *S. parahyba* foram distribuídas nas intensidades de sombreamento (tratamentos): pleno sol, baixa, média e alta (0%, 23%, 67% e 73% de sombreamento, ou 2000, 1540, 660 e 540 μmol.m^{-2}.s^{-1}, respectivamente, mensurados as 11h, horário local, em um dia sem nuvens) obtidas com telas de polietileno. Oitenta dias após a semeadura mediu-se o índice SPAD, a condutância estomática (*gs*), a transpiração (*E*), a fotossíntese (*A*) e a produção de biomassa. Calculou-se também a área foliar específica (AFE) e a alocação de carbono. Os maiores valores da *gs*, *E*, *A* e produção de biomassa foram encontrados a pleno sol, em *P. gigantocarpa*, e ao baixo sombreamento, em *S. parahyba*. O índice SPAD foi maior a pleno sol em ambas as espécies, também sendo maior sob a alta intensidade de sombreamento em *P. gigantocarpa*. Em *P. gigantocarpa* a AFE aumentou com o incremento do sombreamento, enquanto que a alocação de carbono não diferiu entre tratamentos. Em *S. parahyba* a AFE não sofreu efeito dos tratamentos, mas o maior acúmulo de carbono em suas folhas ocorreu com o aumento do sombreamento. As mudas de *P. gigantocarpa* desenvolveram-se melhor a pleno sol e as de *S. parahyba* sob baixa intensidade de sombreamento.

Palavras-chave: índice SPAD, área foliar especifica, fotossíntese.

2.3 INTRODUCTION

Light is one of the most important environmental factors for plant development. Its intensity, duration and quality can change leaf structure and interfere with plant development, influencing many important processes in plants (KOZLOWSKI et al., 1991; SCHLUTER et al., 2003; UNEMOTO et al., 2010). According to Dias-Filho (1999), in tropical forests, light availability is among the major environmental factors that influence growth, reproduction and survival in plants. Therefore, it is essential to know the light requirements of tropical tree species to produce seedlings with high morphophysiological quality (NAKAZONO et al., 2001; NERY et al., 2011).

As reported by Nery et al. (2011), the adaptive plasticity of plant species to different environments, especially to different light conditions, depends on the photosynthetic apparatus adjustment. Therefore, morphophysiological parameters such as chlorophyll content, stomatal conductance, transpiration, photosynthesis, specific leaf area and biomass production, are commonly measured in studies on the adaptation of plant species to different light intensities (MATOS et al., 2011; DUTRA et al., 2012; PIEREZAN et al., 2012).

In the Amazon region, species commonly used in reforestation programs are tree legumes such as *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby (paricá) and some species of the genus Parkia, such as *Parkia gigantocarpa* Ducke (faveira-atanã) (BRIENZA JUNIOR et al., 2008; PERES, 2000). *S. parahyba* has also been indicated to the reforestation of areas originally covered with pastures (LIMA et al., 2003; SABOGAL et al., 2006, CORDEIRO et al., 2009), or to silvipastoral systems (DIAS-FILHO, 2011). This study aims to evaluate the morphophysiological responses of seedlings of *P. gigantocarpa* and *S. parahyba* var. *amazonicum* under different shade intensities, aiming to expand the knowledge about Amazonian tree species and to provide technical support for reforestation programs of these species.

2.4 MATERIAL AND METHODS

The experiment was conducted from June to August 2012, in a semi-controlled environment, in the nursery seedling production unit of Embrapa Amazônia Oriental (01º28'40"S, 48º26'59"W) in Belém, PA, Brazil. The mean air temperature and relative humidity, measured in a agrometeorological station close to the experimental unit, during the experimental period, were 27 ^{o}C and 81%.

Seeds of *Parkia gigantocarpa* Ducke were donated by Cikel Brasil Verde Madeiras Ltda. and seed *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby used in the study were collected from trees grow in the city of Paragominas, PA (02^{o}59'45"S, 47^{o}21'10"W) in the eastern Amazon region.

Prior to sowing, seeds of both species were subjected to mechanical scarification with emery to break dormancy (CRUZ and CARVALHO, 2006). Seeds were sown in plastic trays filled with a substrate composed of sand and sawdust (1:1). Six days after sowing, seedlings were transplanted to black polyethylene bags (15 x 25 cm) with substrate made from a mixture of surface forest soil and sheep manure (3:2). Seedlings were acclimated for 14 days under 75% shade. Fifteen days after sowing, both species were fertilized with 3g of NPK (10-28-20) per bag.

After acclimatization (20 days after sowing), the seedlings were distributed in the following light environments (treatments): full sun, low, medium and high shade intensities (respectively, 0%, 23%, 67% and 73% of shade, or 2000, 1540, 660 and 540µmol.m^{-2}.s^{-1}, at canopy height, measured at 11am, local time, on a cloudless day) obtained with polyethylene screens (Sombrite). Both species remained for 60 days under these treatments. Plants were irrigated once a day, until water saturation of the substrate. At the end of the experiment, 80 days after sowing, we measured the SPAD index of three leaves per plant (youngest leaves, fully formed), yielding an average value of these measurements. We used a portable chlorophyll meter (SPAD-502. Konica Minolta Sensing, INC. Japan) (OLIVEIRA JUNIOR et al., 2011). Stomatal conductance (*gs*), transpiration (*E*) and net photosynthesis (*A*) were measured between 9:00 and 10:00 AM in fully developed and expanded leaves (one leaf per plant), with an infrared gas analyzer (IRGA) (model LCpro, ADC Bioscientific Ltd., UK) under natural CO_2 conditions and a constant photosynthetic active radiation of 500 µmol.m^{-2}.s^{-1} (obtained by an artificial light source coupled to the IRGA chamber). This light level was chosen to mimic the lowest light level used in the experiment. All gas exchange parameters were calculated on a leaf area basis.

Specific leaf area (SLA, the ratio of leaf area to leaf dry mass) was determined over leaf disks (three disks per plant) of either 1.12 cm^2 or 1.65 cm^2, dried at 60 º C until constant mass. Seedlings were harvested and divided into leaves, support tissue (stem and petiole) and roots (obtained by washing the substrate with water). Plant dry mass was obtained by drying the plant material in an oven at 60 º C until constant mass. The carbon allocation pattern was estimated as the leaf, support tissue and root mass ratios (respectively, the ratio between total leaf, stem and petiole or root dry mass per plant and total dry mass per plant).

The experimental design for each species was completely randomized with five replications (one experimental unit = one plant). Data were subjected to analysis of variance and means, with statistical differences, were compared by Tukey test at 5%. All computation of the data was performed by the statistical packace STATISTICA 7.

2.5 RESULTS

In *P. gigantocarpa* the highest SPAD values were found under full sun and at high shade intensity (Figure 1A). In *S. parahyba*, SPAD values were higher in seedlings grown under full sun (Figure 1B).

In *P. gigantocarpa* specific leaf area tended to increase with the increase in shade intensity (Figure 2A). In *S. parahyba*, this response was inconsistent, it was not possible to detect differences among treatments for this parameter (Figure 2B). Biomass production in *P. gigantocarpa* was higher in plants growth under full sun and medium shade intensity (Figure 3A). In *S. parahyba*, the highest biomass production occurred at low and medium shade intensities (Figure 3B).

In *P. gigantocarpa*, carbon allocation did not differ among treatments. In this specie, irrespective of the light environment, carbon was preferentially allocated do leaves (Figure 4A). In *S. parahyba*, the increase in shade intensity tended to increase carbon allocation to the leaves and decrease to roots (Figure 4B).

The highest values of stomatal conductance and transpiration occurred in full sun, in *P. gigantocarpa* and under low-shade in *S. parahyba* (Table 1). The photosynthetic rates of both species were higher in full sun and low-shade (Table 1).

2.6 DISCUSSION

According to Salla et al. (2007) SPAD values can accurately estimate the amount of total chlorophyll in tree species. In the present study, the chlorophyll content (i.e. SPAD values) in seedlings of *P. gigantocarpa* and *S. parahyba* did not follow the expected response observed in tree species, which tend to increase under more intense shade (MATOS et al., 2011; FERREIRA et al., 2012; PIEREZAN et al., 2012).

For Kramer and Kozlowski (1979), in the presence of light the chlorophylls are continuously synthesized and degraded. Degradation is caused by photo-oxidation and tends to increase under higher solar radiation. In the present study, the higher chlorophyll content in *P. gigantocarpa* and *S. parahyba* under full sun (Figure 1) suggests a lower chlorophyll degradation. Interestingly, in *P. gigantocarpa*, high shade plants also showed high SPAD values, suggesting the existence of a compensatory mechanism for capturing light (ALMEIDA et al., 2004; LIMA et al., 2010).

The SLA values found in this study for both species were similar to those reported by Ovington and Olson (1970) for different tropical tree species. The increase in SLA in *P. gigantocarpa* under high shade intensity (Figure 2A) is a common response in forest tree species (CARVALHO et al., 2006; OLIVEIRA and GUALTIERI, 2011; CAMARGO and MARENCO, 2012) to increase the efficiency of light capture (LARCHER, 2006). According Claussen (1996), decreased SLA (thicker or denser leaf) in lighted environments is beneficial to the plant as it exposes less vegetal material per unit of area to solar radiation, due to self-shading of chloroplasts.

The absence of response of SLA to the treatments observed in *S. parahyba* (Figure 2B), corroborates with the results of Matos et al. (2011) and Dutra et al. (2012) who studied seedlings of *Jatropha curcas* L. and *Copaifera langsdorffii* Desf., respectively. Such behavior, in principle, could be interpreted as evidence of a lower plasticity, however, it can also be interpreted as a greater tolerance of these species to different light environments. In *P. gigantocarpa* the increasing in SLA with increasing shade intensity may indicate a higher ecophysiological plasticity.

Because they showed the lowest biomass production under high shade intensity, both *P. gigantocarpa* and *S. parahyba* proved to have low tolerance to low light conditions. This is an expected response of pioneer tree species. According Salisbury and Ross (1992), this occurs because species intolerant low light conditions have high light compensation points, so, as light intensity decreases carbon consumption by respiration will surpass carbon produced by photosynthesis.

The fact that carbon allocation did not differ among treatments in *P. gigantocarpa,* may indicate a lower plasticity of this species, when compared to *S. parahyba*. Unlike *P. gigantocarpa,* carbon allocation in *S. parahyba* followed an expected pattern, suggesting the existence of a compensation mechanism that favors the capture of solar radiation under low light availability (ALMEIDA et al. 2004). Moreover, according to Larcher (2006), when plants are subjected to light conditions that are not adequate for their development, a preferential carbon allocation to the stems may take place.

The higher photosynthetic rates, measured in *P. gigantocarpa* and *S. parahyba* under the highest light intensities, may have contributed to increase biomass production of these species. It could be inferred that the higher *gs* and *E* measured in *P. gigantocarpa* under full sun and *S. parahyba* at low shade intensity may indicate that these light environments were appropriate for these species. Similarly to the present study, *Cupania vernalis* Camb. increases its rate of photosynthesis when grown at higher levels of solar radiation (LIMA-JUNIOR et al., 2006).

2.7 CONCLUSION

The species studied here responded differently to shade intensity. Although both species can be classified as heliophyte plants, *P. gigantocarpa* seedling should be preferentially formed under full sun, while low shade intensity is the preferential environment for *S. parahyba* seedling formation.

2.8 ACKNOWLEDGEMENTS

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Figures

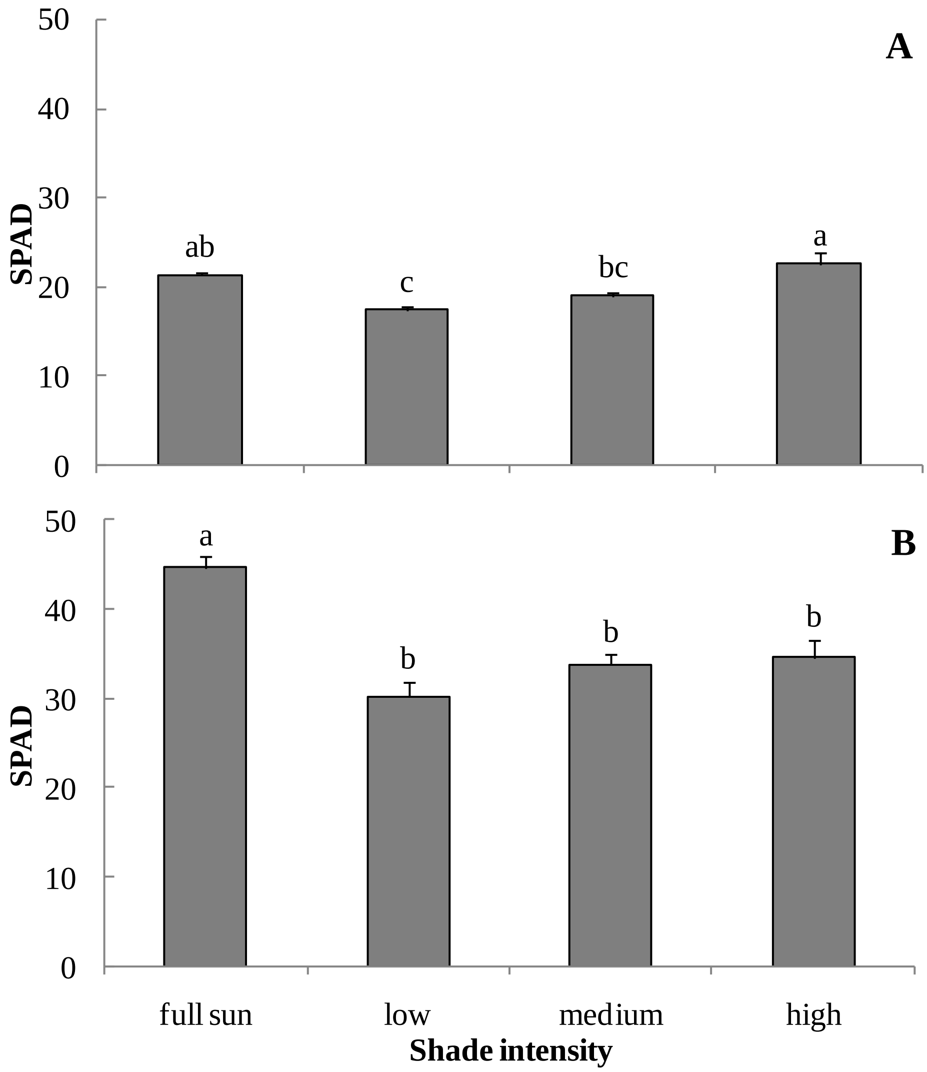

Figure 1 - SPAD values of *P. gigantocarpa* (A) and *S. parahyba* (B) under different shade intensities. Date are means ± standard error (n=5). Columns with different letters are significantly different (P<0.05, Tukey test).

Figura 1*- Valores de SPAD de P. gigantocarpa (A) e S. parahyba (B) cultivadas sob diferentes intensidades de sombreamento. Média ± erro padrão (n=5). Colunas com letras diferentes apresentam diferenças significativas (P<0.05, teste de Tukey).*

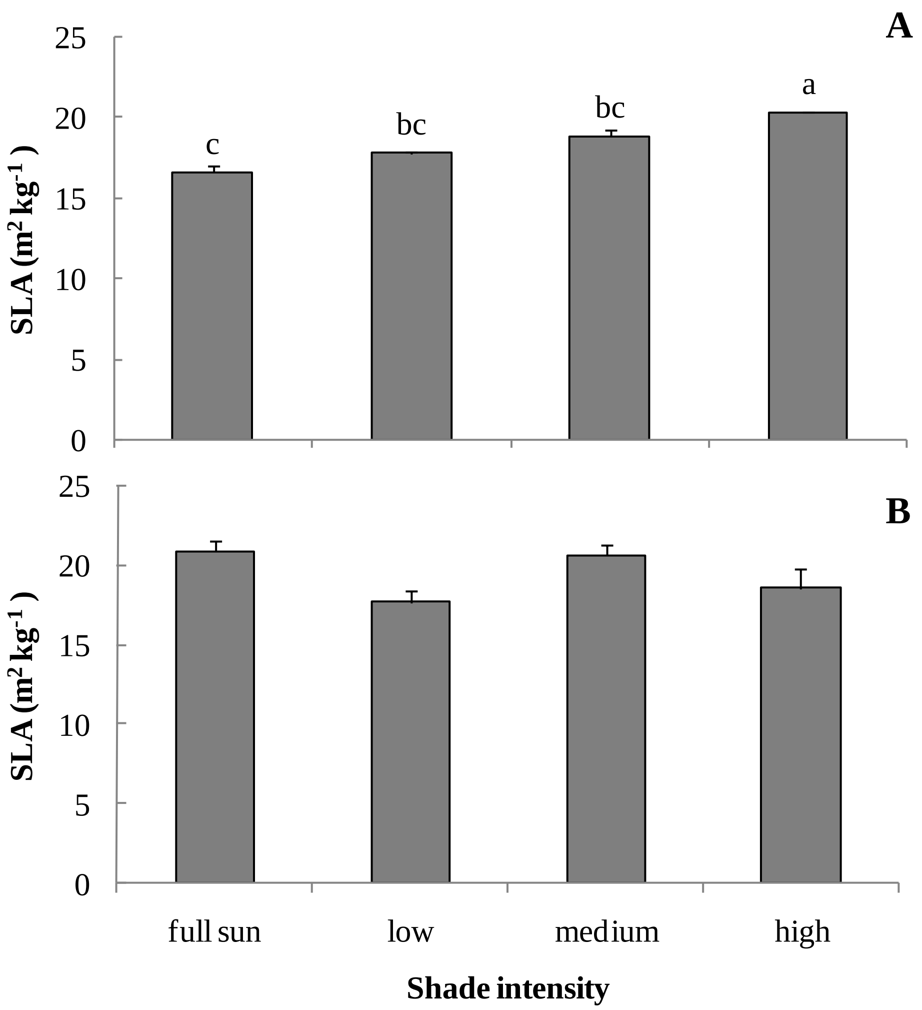

Figure 2 - Specific leaf area (SLA) of *P. gigantocarpa* (A) and *S. parahyba* (B) under different shade intensities. Date are means ± standard error (n=5). Columns with different letters are significantly different ($P<0.05$, Tukey test).

Figura 2 *– Área foliar específica (SLA) de P. gigantocarpa (A) e S. parahyba (B) cultivadas sob diferentes intensidades de sombreamento. Média ± erro padrão (n=5). Colunas com letras diferentes apresentam diferenças significativas (P<0.05, teste de Tukey).*

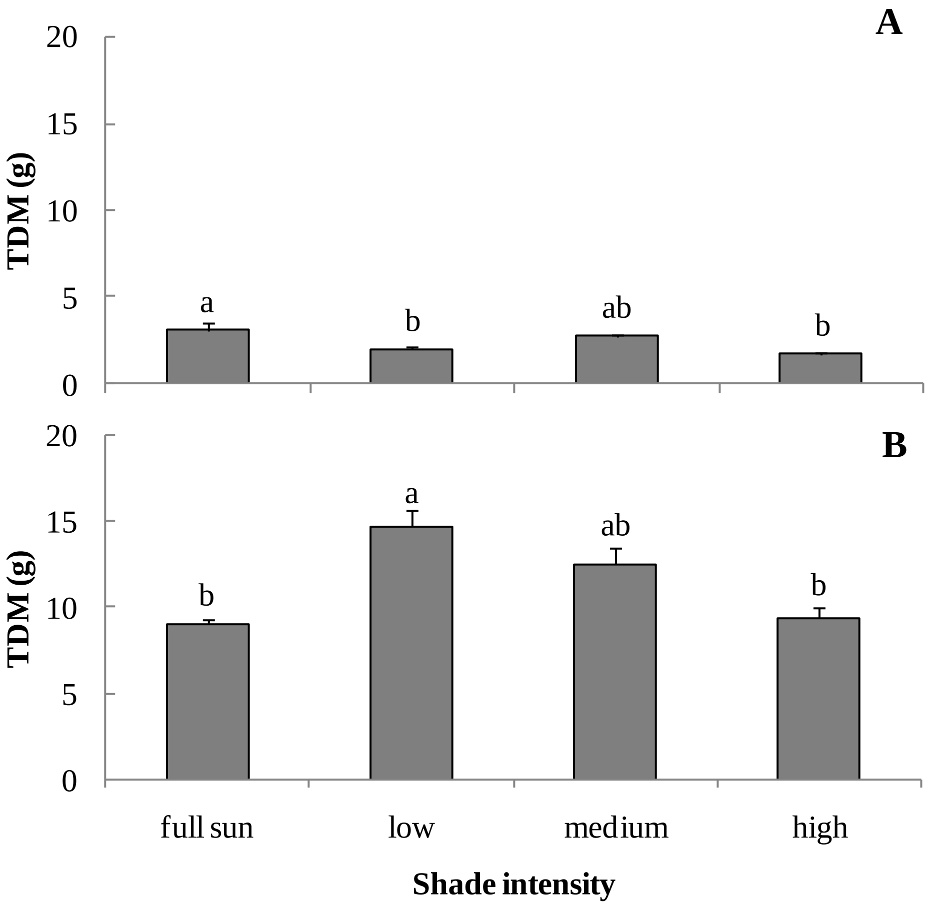

Figure 3 - Total dry matter (TDM) of *P. gigantocarpa* (A) and *S. parahyba* (B) under different shade intensities. Date are means ± standard error (n=5). Columns with different letters are significantly different (P<0.05, Tukey test).

Figura 3 *– Massa seca total (TDM) de P. gigantocarpa (A) e S. parahyba (B) cultivadas sob diferentes intensidades de sombreamento. Média ± erro padrão (n=5). Colunas com letras diferentes apresentam diferenças significativas (P<0.05, teste de Tukey).*

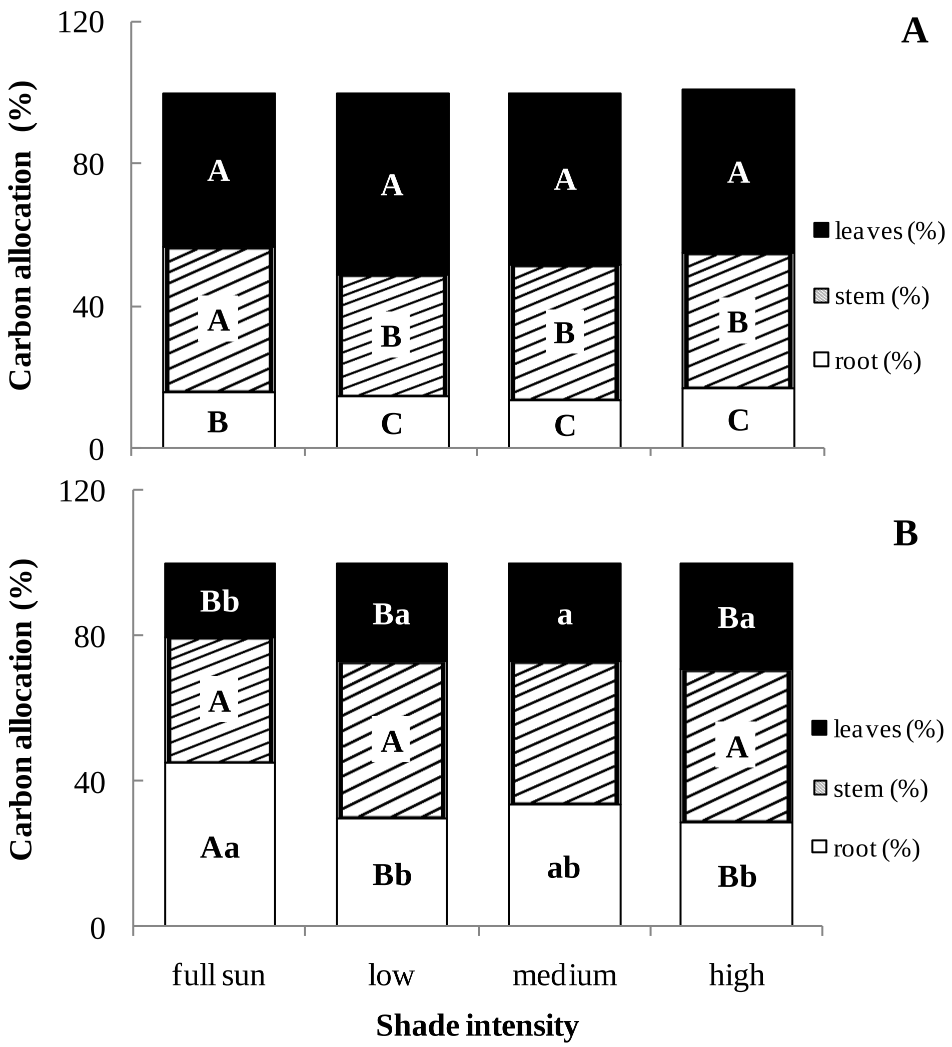

Figure 4 - Carbon allocation of *P. gigantocarpa* (A) and *S. parahyba* (B) under different shade intensities. Different upper-case letters within columns indicate significant differences among plant organs (P<0.05, Tukey test). Lower-case letters among columns indicate significant differences among treatments (P<0.05, Tukey test).

Figura 4 *- Alocação de carbono em P. gigantocarpa (A) e S. parahyba (B) cultivadas sob diferentes intensidades de sombreamento. Diferentes letras maiúsculas dentre colunas indicam diferença significativa dentre órgãos vegetais (P<0.05, teste de Tukey). Diferentes letras minúsculas entre colunas indicam diferença significativa dentre tratamentos (P<0.05, teste de Tukey).*

Table

Table 1 - Stomatal conductance (*gs*), transpiration (*E*) and net photosynthesis rates (*A*) of *P. gigantocarpa* and *S. parahyba* under different shade intensities.

Tabela 1- *Condutância estomática (gs), transpiração (E) e taxa fotossintética (A) de P. gigantocarpa e S. parahyba cultivadas sob diferentes intensidades de sombreamento.*

Species	Shade Intensity	*gs* (molm^{-2}s^{-1})	*E* (mmol m^{-2} s^{-1})	*A* (μmol m^{-2} s^{-1})
	Full Sun	0.067 (± 0.004) a	1.48 (± 0.07) a	3.39 (± 0.36) a
P. gigantocarpa	Low	0.027 (± 0.006) b	0.58 (± 0.13) b	2.98 (± 0.63) a
	Medium	0.010 (± 0.000) b	0.12 (± 0.03) b	0.75 (± 0.14) b
	High	0.017 (± 0.002) b	0.24 (± 0.05) b	1.79 (± 0.19) b
	Full Sun	0.120 (± 0.008) b	2.057 (± 0.15) b	5.62 (± 0.18) a
S. parahyba	Low	0.208 (± 0.051) a	3.423 (± 0.56) a	6.43 (± 0.06) a
	Medium	0.072 (± 0.011) b	1.686 (± 0.11) b	4.89 (± 0.33) b
	High	0.075 (± 0.021) b	1.424 (± 0.39) b	4.42 (± 0.55) b

*Values are means ± standard error (n=5). Means followed by different letters in each column are significantly different (P<0.05, Tukey test).

**Valores representam a média ± erro padrão (n=5). Médias seguidas de letras diferentes, dentre cada coluna, apresentam diferenças significativas (P<0.05, teste de Tukey).*

3 Morphophysiological behavior and cambial activity in seedlings of two Amazonian tree species under shade

3.1 Abstract

Variations in light intensity can lead to important anatomical and morphophysiological changes in plants. Aiming to increase knowledge about the Amazonian tree species, this study examines the influence of shade on the cambial activity and development of *Parkia gigantocarpa* Ducke and *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby seedlings grown in a nursery. Twenty days after sowing, seedlings of *P. gigantocarpa* and *S. parahyba* were allocated to the following light environments (treatments): full sun, low, medium and high shade intensity (respectively, 0%, 23%, 67% and 73% of shade, or 2000, 1540, 660 and 540μmol.m^{-2}.s^{-1}, at canopy height, measured at 11am, local time, on a cloudless day) obtained with polyethylene screens. After seedling have remained 60 days under these treatments, we measured plant height, stem diameter, biomass production, stomatal conductance (*gs*), transpiration (*E*), photosynthesis (*A*) and cambial activity (xylem, cabium and phloem). Also, we calculated the Dickson quality index (DQI). The highest values of biomass production, *gs*, *E*, *A* and DQI were found under full sun, in *P. gigantocarpa*, and under low shade intensity in *S. parahyba*. In both species high shade intensity reduced cambial activity. We concluded that the cambial activity, the physiological and morphological attributes work together, explaining the radial growth and increasing seedlings quality, which was optimized under full sun, in *P. gigantocarpa*, and under low shade intensity in *S. parahyba*.

Key-words: *Parkia gigantocarpa, Schizolobium parahyba*, light, photosynthesis, xylem

3.2 Introduction

Although environmental factors do not operate alone in plants, light is particularly important as it is the direct source of energy for photosynthesis, influencing plant growth (Valladares and Niinemets 2008; Goh et al. 2012). However, all plants possess some degree of plasticity to more efficiently use solar radiation (Semchenko et al. 2012; Houter and Pouns 2012). This is commonly observed in studies of forest tree species under restricted light conditions (Kitajima 1994; Azevedo et al. 2010, Aguiar et al. 2011; Dutra et al. 2012; Pierezan et al. 2012). According to these studies, stem diameter is commonly measured, because its development is essential for growth, ensuring plant survival in the field under environmental stress and is also important for wood formation (Downes et al. 2009; Speck and Burgert 2011).

Variation in stem diameter in response to light is a form of environmental adaptation that probably occurs because of cambial activity, which is stimulated by carbohydrates produced by photosynthesis, and hormonal activity (Terrazas et al. 2011; Dayan et al. 2012). According to Dejardin et al. (2010), increased cambial activity amounts to produce xylem, thus increasing radial growth (i.e, stem diameter), resulting in wood formation. Cambial activity can be influenced by environmental factors such as light, and by intrinsic factors to the plant, such as genetics and physiology (Risopatron et al. 2010; Terrazas et al. 2011). Since cambial activity is affected by light, it could be suggested that seedling quality would also be affected by this environmental factor.

Thus, in order to expand the knowledge on the anatomical and morphophysiological responses of Amazonian Leguminosae tree species to shade, aiming to devise a more efficient seedling production strategy, this study intends to examine the influence of shade intensity on cambial activity and on morphological and physiological characteristics of seedlings of *Parkia gigantocarpa* Ducke and *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby grown in a nursery.

3.3 Materials and methods

The experiment was conducted from June to August 2012, in a semi-controlled environment, in the nursery seedling production unit of the Plant Ecophysiology Laboratory of Embrapa Amazônia Oriental (01º28'40"S, 48º26'59"W) in Belém, PA, Brazil. The mean air temperature and relative humidity, measured in a agrometeorological station close to the experimental unit, during the experimental period, were 27 ^{o}C and 81%.

Seeds of *Parkia gigantocarpa* Ducke were donated by Cikel Brasil Verde Madeiras Ltda. and seed *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby used in the study were collected from trees grow in a reforested area, close to the city of Paragominas, PA (02^{o}59'45"S, 47^{o}21'10"W) in the eastern Brazilian Amazon.

Prior to sowing, seeds of both species were subjected to mechanical scarification with emery to break dormancy. Six days after sowing, seeds were sown in plastic trays filled with a substrate composed of sand and sawdust (1:1). Seedlings were transplanted to black polyethylene bags (15 x 25 cm) with substrate made from a mixture of surface forest soil and sheep manure (3:2). Seedlings were acclimated for 14 days under 75% shade intensity. Fifteen days after sowing, both species were fertilized with 3g of NPK (10-28-20) per plant.

After acclimation (20 days after sowing), seedlings were distributed in the following light environment (treatments): full sun, low, medium and high shade intensities (respectively, 0%, 23%, 67% and 73% of shade, or 2000, 1540, 660 and 540μmol.m^{-2}.s^{-1}, at canopy height, measured at 11am, local time, on a cloudless day) obtained with polyethylene screens (Sombrite). *P. gigantocarpa* and *S. parahyba* remained for 60 days under these light environments. Plants were irrigated once a day, until water saturation of the substrate.

Morphological parameters

Stem diameter (D) was measured near the substrate level; on two opposite points at the same height with a digital caliper to an accuracy of 0.01 mm. The mean D was the average of these two points. Seedling height (H) was measured with a ruler, from the level of the substrate to the apical bud. Both D and H were measured when plants were for 15 and 60 days under the treatments. Based on data collected at the second time of collection, we calculated the ratio H/D.

At the end of the experiment (60 days under the treatments), plants were cut and fractionated into leaves, stems and roots. Plant dry mass was obtained by drying the plant material in an oven at 60 º C until constant mass. Total dry mass (TDM) was calculated by adding leaf dry mass (LDM), stem dry mass (SDM) and root dry mass (RDM). Aerial dry mass (ADM) was obtained by adding LDM and SDM.

Dickson Quality Index (DQI = [TDM (g) / [(H (cm) / D (mm)) + (ADM (g) / RDM (g))]) was calculated according to Dickson et al. (1960).

Physiological parameters

Stomatal conductance (*gs*), transpiration (*E*) and net photosynthesis (*A*) were measured at the end of the experiment (60 days under the treatments), between 9:00 and 10:00 AM, in fully developed and expanded leaves, with an infrared gas analyzer (IRGA) (model LCpro, ADC Bioscientific Ltd., UK) under natural CO_2 conditions and photosynthetic active radiation of 500 μmol.m^{-2}.s^{-1} (obtained by an artificial light source coupled to the IRGA chamber). This light level was chosen to mimic the lowest light level used in the experiment. All gas exchange parameters were calculated on a leaf area basis.

Anatomical parameters

To analyze cambial activity (CA) in the stem, plants were sampled on two occasions: 15 days and 60 days after the imposition of the treatments. After the stems have been collected, fragments located between the first node and the substrate level were selected and preserved in ethyl alcohol 70% (Berlyn and Miksche 1976).

For the preparation of the slide collection, sections were cleared by immersion in a sodium hypochlorite solution and then washed with distilled water. Subsequently, they were stained with safranin (1%) and Astra blue (1%) (Bukatsch 1972). Semi-permanent slides, freehand sections of the stem cross sections were prepared with glycerin. In sectioned samples were measured structures derived from the cambial activity that is the vascular system formed by xylem, cambium and phloem, with the aid of an objective and eyepiece 10 x micrometer microscope Zeiss Axiolab. Photographs were obtained from a 3.0 M pixel camera (Moticam).

Experimental design and statistical analysis

The experimental design for each species was completely randomized with five replicates (one experimental unit = one plant) for H/D, biomass production, photosynthesis, stomatal conductance, transpiration and Dickson quality index and completely randomized in a 4x2 factorial arrangement (treatment x evaluation period), with five replicates for H, D and cambial activity. Data were subjected to analysis of variance and, when appropriate, the means were compared by Tukey test at 5%. Correlation analysis between cambial activity, D, SDM, TDM, DQI, *A*, *gs* and *E* was calculated by parametric (Pearson correlation) or nonparametric (Spearman correlation) statistics, according to the nature of the data. All statistical calculations were performed by the software STATISTICA 7.

3.4 Results

For both species, there was no evaluation period x treatment interaction for plant height and stem diameter. However, when each evaluation period was considered individually, significant differences among treatments were found for these variables (Fig. 1). For the first evaluation period, the highest values of plant height were measured in full sun plants of both species. Plant diameter did not vary among treatments in *P. gigantocarpa*, however, in *S. parahyba* stem diameter were larger for full sun and low shade intensity plants. In the second evaluation period, both species maintained the greatest plant heights under full sun, but in *P. gigantocarpa* this greater plant height was also shared by plants grown under low and high shade intensity, while in *S. parahyba*, plants were also higher under medium and high shade intensity. Also, in the second evaluation period, stem diameter in *P. gigantocarpa* was lower under high shade intensity. In *S. parahyba* stem diameter did not differ among treatments, but tended to be higher in plants grown under low shade intensity. The ratio H/D was greater under high shade intensity in *P. gigantocarpa*, but did not differ among treatments in *S. parahyba* (Fig. 1).

In *P. gigantocarpa* leaf dry mass and stem dry mass were lower under high shade intensity. Stem dry mass was also lower in low shade intensity plants (Table 1). In *S. parahyba* leaf dry mass was higher under medium shade intensity and the stem dry mass was higher under low and medium shade intensity. In both species root dry mass tended to decrease under high shade and the ratio ADM/RDM was not affected by treatments. The total dry mass was higher under full sun and medium shade intensity in *P. gigantocarpa* and under low and medium shade intensity in *S. parahyba* (Table 1).

Dickson quality index in *P. gigantocarpa* ranged from 0.19, in high shade intensity, to 0.31, in full sun. In *S. parahyba* this index ranged from 1.05, in high shade intensity plants, to 1.81, in low shade intensity plants (Fig. 2).

Stomatal conductance and transpiration were higher under full sun in *P. gigantocarpa* and under low shade intensity in *S. parahyba*. The highest photosynthetic rates were measured under full sun and low shade intensity in both species (Fig. 3).

For both species, there was no evaluation period x treatment interaction for cambial activity. However, when each evaluation period was considered individually, significant differences among treatments were found for these variables. On both evaluation periods, the cambial activity was reduced on high shade intensity plants of both species (Fig. 4, 5 and 6). For both species the cambial activity correlated positively with vegetative growth and physiological parameters (Table 2).

In *P. gigantocarpa*, stem cross section made on the first evaluation period (Fig. 5 a-d, i), revealed tector trichomes, epidermis with polygonal cells, principle of lenticels; cortex with angular collenchyma without intercellular spaces, followed by layers of isodiametric parenchyma cells with intercellular spaces (Fig. 5 i, j). Sequentially, we observed sclerenchyma bands adjacent to the vascular system. This vascular system showed the greatest development in seedlings grown under full sun, resulting from the greater cambial activity (ca. 500µm). In the second evaluation period (Fig. 5 e-h, j), we noted the periderm, isodiametric parenchyma cells with smaller intercellular spaces, sclerenchyma cap and increased vascular system, consisting of phloem, cambium, xylem and medulla. This vascular system, measured in the second evaluation period, was higher in seedlings under lower shade intensity, resulting from the greater cambial activity (ca. 800µm) (Fig. 4a).

In *S. parahyba*, stem cross section revealed absence of trichomes. In the first evaluation period, we found that the cortex is composed of isodiametric parenchyma cells without intercellular spaces, sclerenchymatic cap interrupted, followed by phloem, cambium, xylem and medulla (Fig. 6 a-d, i). The highest values of cambial activity were close to 800µm, which were measured in plants grown under full sun and at low shade intensity. In the second evaluation period (Fig. 6 e-h, j), we observed that the stem was composed of periderm, lenticels, smaller area layers of parenchyma cells and well-developed vascular system, resulting from the high cambial activity (ca. 2500µm), tending to be higher in low shade intensity plants (Fig. 4). In the second evaluation period, cambial activity was lower under high shade intensity in *P. gigantocarpa* and tended to decrease in *S. parahyba*. On both evaluation periods and on both species, the cambium was already well developed, with the complete ring cambium in full activity.

3.5 Discussion

Vegetative growth

Plant height growth of *P. gigantocarpa* and *S. parahyba* did not follow the expected response pattern. According to Sultan (2010), there is a higher stem elongation under low light intensity, resulting in greater height. Studies conducted with forest species, indicate that this strategy is an adaptive mechanism to low light environments (Ferreira et al. 2012; Pierezan et al. 2012; Dutra et al. 2012). However, in the present study, the absence of a higher stem elongation in low light plants from both species could indicate a differential adaptive mechanism to low light environments. Similar results were found in *Caesalpinia ferrea* Mart. ex Tul. (Lima et al. 2008) and in *Talisia subalbens* (Mart.) Radlk. seedlings (Nery et al. 2011).

The increase in stem diameter in *P. gigantocarpa* under full sun (Fig. 1) is a common response in forest species (Aguiar et al. 2011; Roweder et al. 2011; Ferreira et al. 2012). However, some forest species do not vary stem diameter in response to light availability (Almeida et al. 2004; Ortega et al. 2006; Dutra et al. 2012), corroborating the lack of response found in *S. parahyba* (Fig. 1).

The ratio between height and diameter (Fig. 1) indicated that *P. gigantocarpa* achieved an adequate growth balance under lower shade intensity, while in *S. parahyba* this balance was achieved in plants grown under low shade intensity.

Biomass production

The pattern of biomass production *P. gigantocarpas* and *S. parahyba* (Table 1) suggests low shade tolerance. Similar results are also reported for seedlings of the forest species *Caesalpinia ferrea* Mart. Ex Tul. (Lima et al. 2008), *Simarouba amara* Aubl. (Azevedo et al. 2010) and *Talisia subalbens* (Mart.) Radlk. (Nery et al. 2011). In the present study, both species tended to increase root biomass under higher light intensities. Possibly, this behavior was an acclimation strategy to increase water uptake in response to increased transpiration and thus to soil drying (Sultan 2003). In both species the variation of light did not affect the ratio between aerial dry mass and root dry mass (Table 1), suggesting a certain balance in the biomass distribution of these species under this abiotic stress. Similar behavior was also found in studies with forest seedlings (Nery et al. 2011; Dutra et al. 2012).

Seedling quality

Based on the ideal minimum DQI value of 0.20, suggested by Hunt (1990), it is reasonable to infer that when grown under full sun, seedlings of *P. gigantocarpa* would have a better quality for reforestation. For *S. parahyba*, although the DQI values for all treatments were always above the minimum ideal value suggested by Hunt (1990), these values were higher under low shade intensity (Fig. 2), which could be considered as the adequate light environment for the production of seedlings of this species. Similarly, Melo et al. (2008) and Aguiar et al. (2011), studying *Enterolobium contortisiliquum* (Vell.) and *Caesalpinia echinata* Lam under different light intensities, considered higher DQI values (greater than 0.20), as the seedlings with the best quality for reforestation purposes.

Stomatal conductance, transpiration and photosynthesis

One of the first responses of plants to environmental stress is a reduction in stomatal conductance (Centrito 2003). Therefore, it can be inferred that because the highest stomatal conductance values for *P. gigantocarpa* were found under full sun, and for *S. parahyba* were measured under low shade intensity, these light environments were adequate for these species, allowing a greater stomata aperture and increased transpiration. Based on the gas exchange behavior of the studied species, it can be concluded that these tropical forest species require high light intensities for maximum photosynthesis rates (Fig. 3). Accordinly, *Cupania vernalis* Camb. (Lima-Junior et al. 2006) and *Dipteryx alata* Vog. (Mota et al. 2012) show higher gas exchance values when grown at higher light intensity.

Cambial activity

The higher vascular system development under increasing light observed in the studied species (Fig. 4) could be explained by the role of light in affecting cambial activity by interacting with hormones, such as auxin (Risopatron et al. 2010) and gibberellin (Dayan et al. 2012), stimulating photosynthesis and increasing the carbohydrate production that may be used to xylem and phloem build up. Furthermore, environmental factors are known to affect the size and organization of the vascular elements (Carlquist 2001; Alves and Angyalloss-Alfonso 2000) in order to ensure adequate transport in conducting vessels, especially when the plant is subject to stress. Other studies also found the influence of environmental factors on the development and structure of the vascular system, which is derived from the cambial activity (Wani and Khan 2010; Terrazas et al. 2011; Gea-Izquierdo et al. 2012; Gebauer et al. 2012).

Cambial activity, physiological parameters and plant growth

The positive correlation of the cambial activity with physiological (photosynthesis, stomatal conductance and transpiration), morphological (stem diameter, stem dry mass and total dry mass) and anatomical (cambial activity) parameters (Table 2) of *P. gigantocarpa* and *S. parahyba*, suggested that the development of these forest seedlings is greatly affected by the cambium activity.

The higher cambial activity and the consequent increase in xylem production observed for both species in the least shaded environments, probably increased the pressure gradient in the phloem, as a result of the sugars loading and unloading (Santiago et al. 2004; Holtta et al, 2010). Thus, it could be inferred that in less shaded environments, increased cambial activity and, consequently, higher shoot development might have stimulated the photosynthetic rate. This happens because stem thickening increases the demand for photosynthates, because the stem is the preferred drain in the vegetative plant stage (Sone et al., 2005). Finally, the higher cambial activity increased stem biomass and diameter, resulting in better seedlings quality.

It is also important to note that environmental factors affect this mechanism. In the present study the highest shade intensity reduced cambial activity, decreased gas exchange and biomass production, resulting in reduced seedlings quality of both species, which would likely decrease their survival in the field. Therefore, we concluded that the cambial activity, the physiological and morphological attributes work together, explaining the radial growth and increasing seedlings quality (adequate Dickson quality index), which was optimized under full sun, in *P. gigantocarpa*, and under low shade intensity in *S. parahyba*.

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Figures

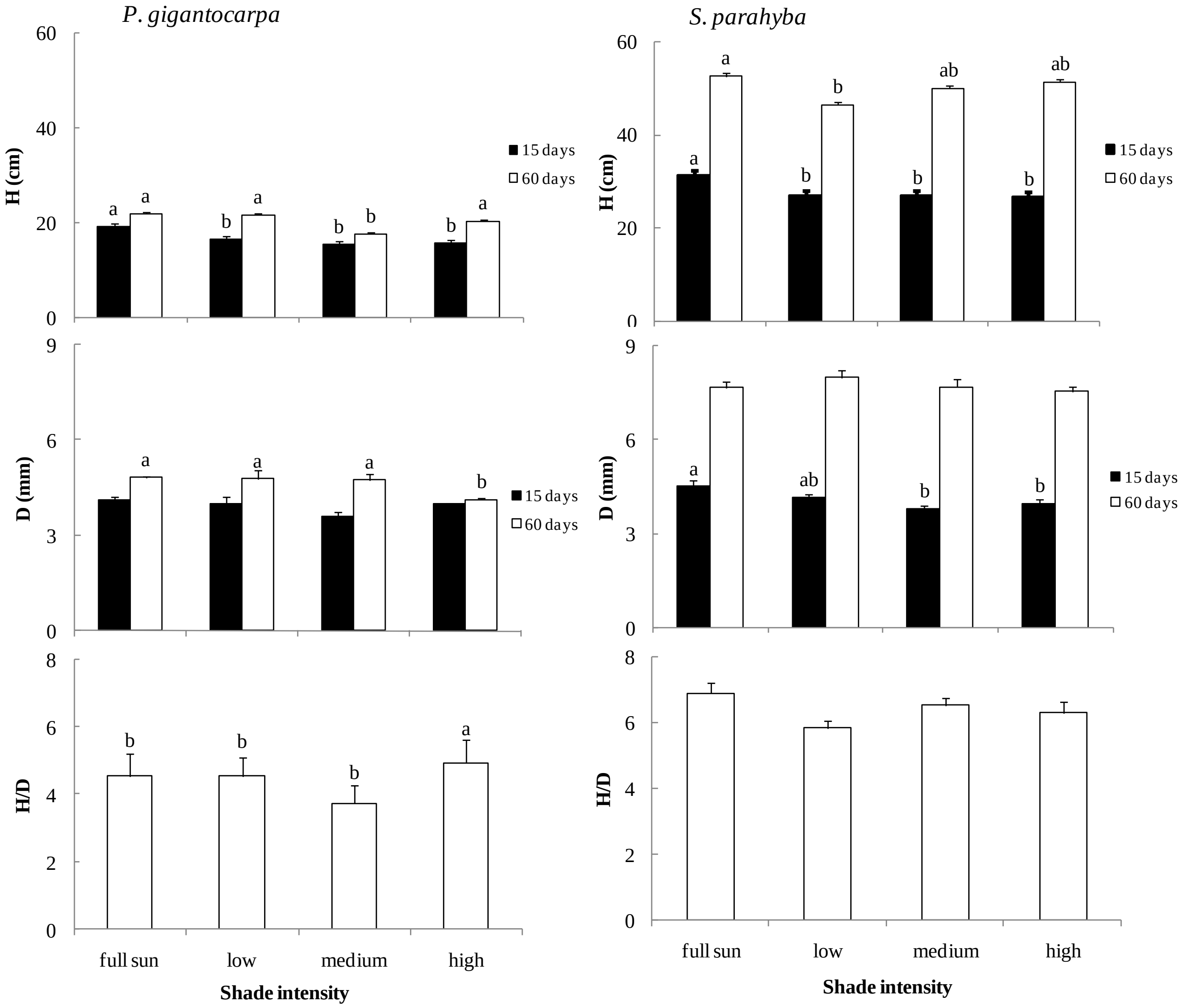

Fig. 1 Height (H), diameter (D) and the ratio H/D of *P. gigantocarpa* and *S. parahyba* under different shade intensities. Means ± standard error (n = 5). Columns with different letters, within the same evaluation period, are significantly different (P < 0.05, Tukey test).

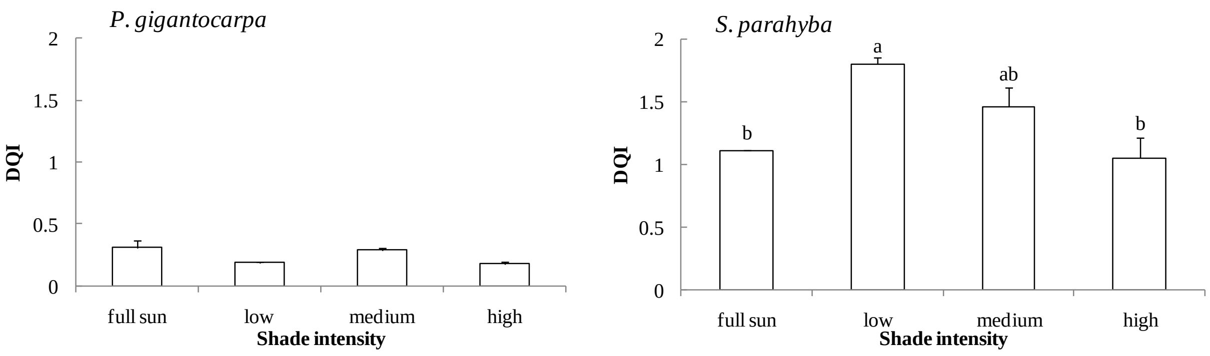

Fig. 2 Dickson Quality Index (DQI) of *P. gigantocarpa* and *S. parahyba* under different shade intensities. Means ± standard error (n = 5). Columns with different letters are significantly different (P < 0.05, Tukey test).

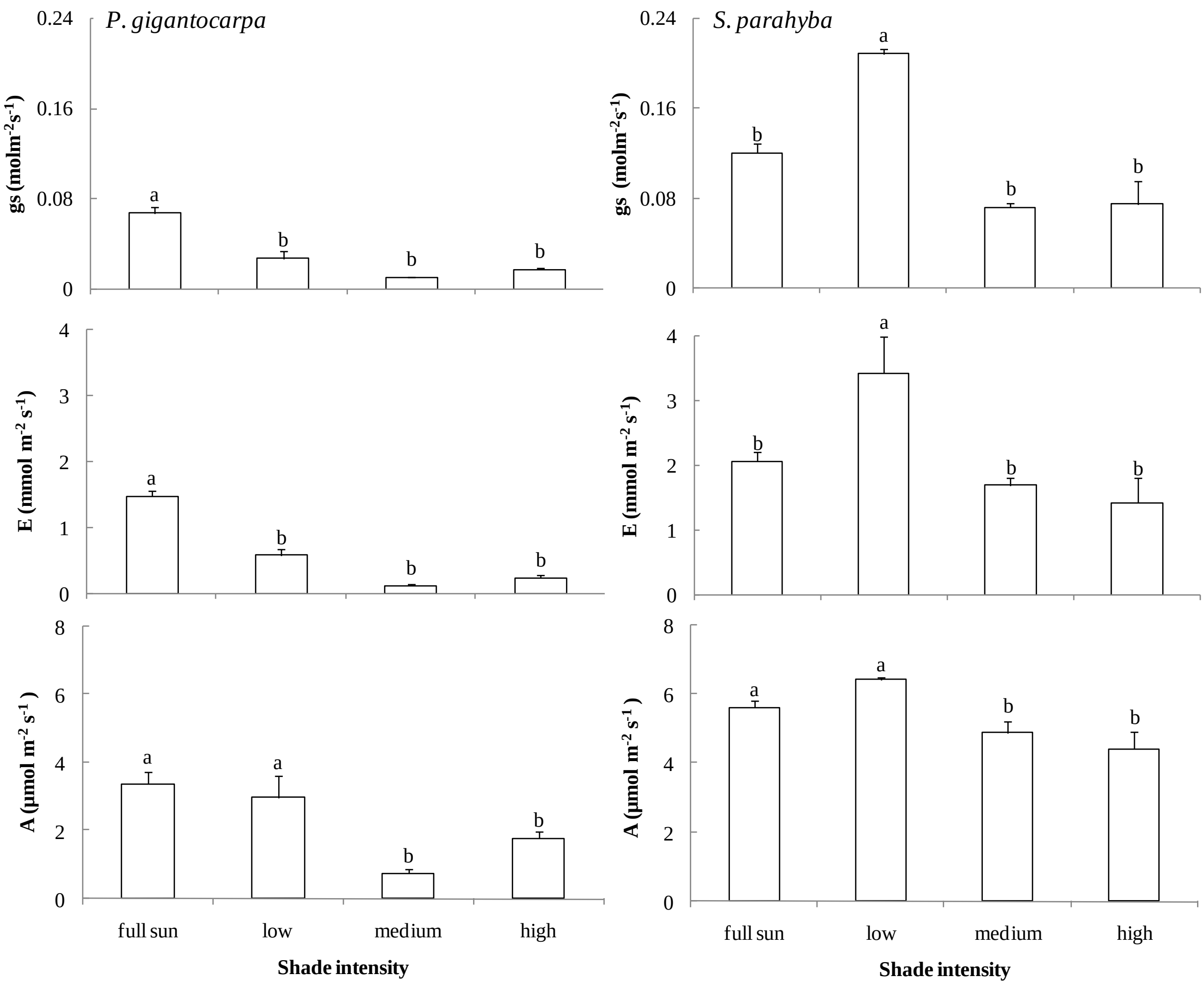

Fig. 3 Stomatal conductance (*gs*), transpiration (*E*) and net photosynthesis (*A*) of *P. gigantocarpa* and *S. parahyba* under different shade intensities. Means ± standard error (n = 5). Columns with different letters are significantly different (P < 0.05, Tukey test).

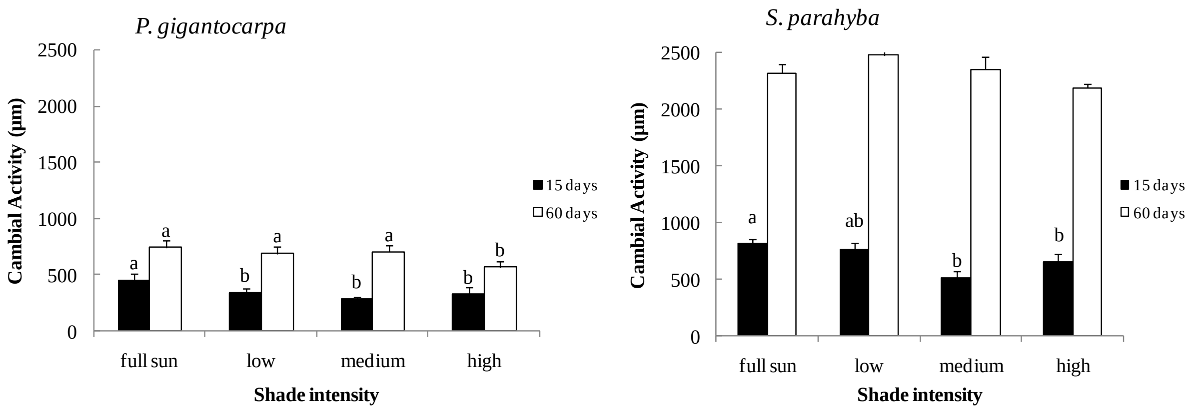

Fig. 4 Cambial activity of *P. gigantocarpa* and *S. parahyba* under different shade intensities. Means ± standard error (n = 5). Columns with different letters, within the same evaluation period, are significantly different (P < 0.05, Tukey test).

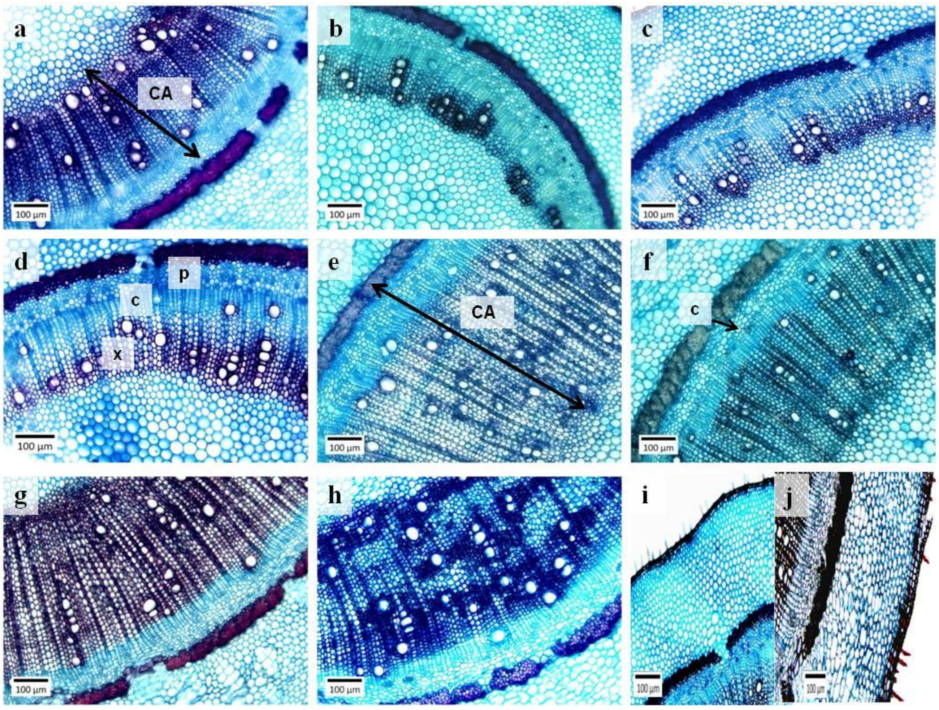

Fig. 5 *P. gigantocarpa* cross sections stem. (a-d, i) plants 15 days under different shade intensities. (e-h, j) plants 60 days under different shade intensities. Seedlings in full sun (a, e) low (b, f), medium (c, g) and height (d, h) shade intensity. (i, j) Epidermis and cortex. Cambial activity (CA), xylem (x), cambium (c) and phloem (p).

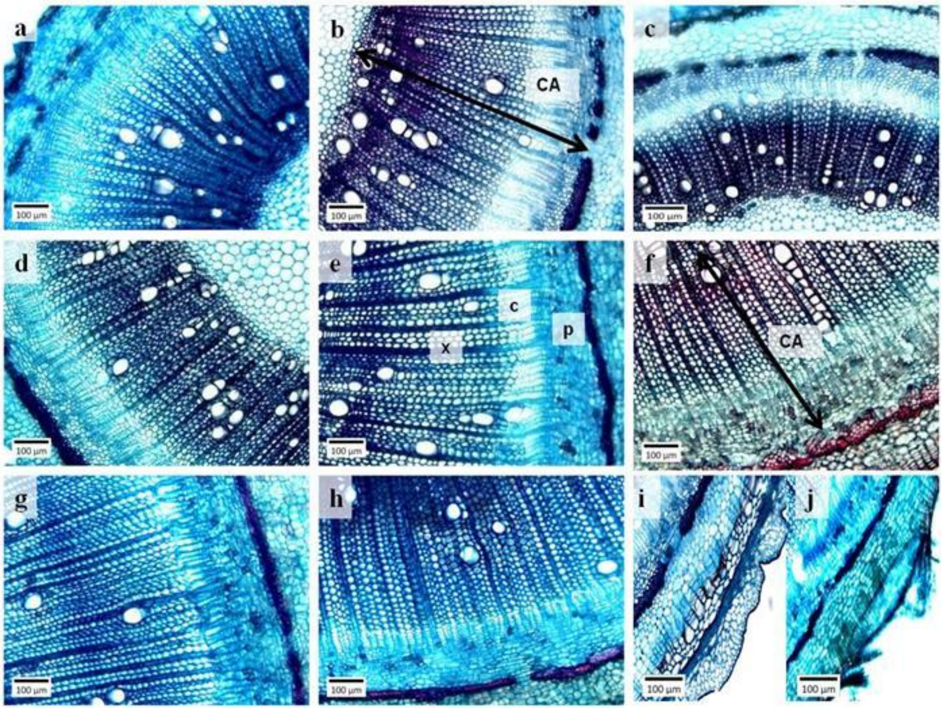

Fig. 6 *S. parahyba* cross sections stem. (a-d, i) plants 15 days under different shade intensities. (e-h, j) plants 60 days under different shade intensities. Seedlings in full sun (a, e) low (b, f), medium (c, g) and height (d, h) shade intensity. (i, j) Epidermis and cortex. Cambial activity (CA), xylem (x), cambium (c) and phloem (p).

Tables

Table 1 Biomass production of *P. gigantocarpa* and *S.parahyba* under different shade intensities. Leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), total dry mass (TDM) aerial dry mass (shoot, ADM) and the ratio between ADM and RDM.

Species	Shade intensity	LDM (g)	SDM (g)	RDM (g)	TDM (g)	ADM/RDM
P. gigantocarpa	Full sun	1.33 (± 0.17) a	1.28 (± 0.21) a	0.50 (± 0.12)	3.11 (± 0.44) a	5.22 (± 0.76)
	Low	1.01 (± 0.04) ab	0.71 (± 0.06) b	0.31 (± 0.02)	2.03 (± 0.12) b	5.55 (± 0.15)
	Medium	1.35 (± 0.04) a	1.05 (± 0.01) ab	0.39 (± 0.02)	2.79 (± 0.04) ab	6.15 (± 0.53)
	High	0.80 (± 0.01) b	0.66 (± 0.03) b	0.30 (± 0.03)	1.76 (± 0.03) b	4.87 (± 0.61)
S. parahyba	Full Sun	1.83 (± 0.01) d	3.11 (± 0.19) b	4.12 (± 0.39) a	9.06 (± 0.19) b	1.20 (± 0.17)
	Low	3.99 (± 0.25) a	6.30 (± 0.70) a	4.40 (± 0.03) a	14.69 (± 0.92) a	2.34 (± 0.23)
	Medium	3.31 (± 0.04) b	4.78 (± 0.23) ab	4.42 (± 0.92) a	12.51 (± 0.98) ab	1.83 (± 0.38)
	High	2.63 (± 0.03) c	3.86 (± 0.16) b	2.86 (± 0.43) b	9.35 (± 0.62) b	2.27 (± 0.33)

*Values are means ± standard error (n = 5). Means followed by the different letter in each column are significantly different (P<0.05, Tukey test).

Table 2 Correlation coefficient (r) of the correlations between stem diameter (D), total dry mass (TDM), shoot dry weight (SDM), Dickson quality index (DQI), photosynthesis (A), stomatal conductance (gs) or transpiration (E) vs. cambial activity of *P. gigantocarpa* and *S. parahyba* (n=5).

Parameters	*P. gigantocarpa*	*S. parahyba*
	r	**r**
D	0.80[1]	0.94[1]
SDM	0.34	0.68
TDM	0.45	0.80
DQI	0.38	0.86
A	0.35	0.88
gs	0.21	0.75
E	0.27	0.83

[1] Results obtained by non-parametric correlations analysis

CONCLUSÕES GERAIS

A atividade cambial, os parâmetros fisiológicos e morfológicos atuam em conjunto na qualidade de mudas. Mudas de melhor qualidade são obtidas em *P. gigantocarpa*, a pleno sol e em *S. parahyba*, a baixa intensidade de sombreamento (23% de sombreamento).

ANEXOS

Normas de publicação

1. Revista árvore

O Manuscrito deverá apresentar as seguintes características: espaço 1,5; papel A4 (210 x 297 mm), enumerando-se todas as páginas e as linhas do texto, páginas com margens superior, inferior, esquerda e direita de 2,5 cm; fonte Times New Roman 12; e conter no máximo 16 laudas, incluindo tabelas e figuras. Tabelas e figuras devem ser limitadas a 5 no conjunto. Manuscritos com mais de 16 laudas terão custos adicionais de submissão cobertos pelo(s) autor(es), na base de R$40,00/página.

Na primeira página deverá conter o título do manuscrito, o resumo e as três (3) Palavras-Chaves.

Não se menciona os nomes dos autores e o rodapé com as informações, para evitar a identificação dos mesmos pelos Pareceristas.

Nos Manuscritos em português, os títulos de tabelas e figuras deverão ser escritos também em inglês; e Manuscritos em espanhol e em inglês, os títulos de tabelas e figuras deverão ser escritos também em português. As tabelas e as figuras deverão ser numeradas com algarismos arábicos consecutivos, indicados no texto e anexados no final do Manuscrito. Os títulos das figuras deverão aparecer na sua parte inferior antecedidos da palavra Figura mais o seu número de ordem. Os títulos das tabelas deverão aparecer na parte superior e antecedidos da palavra tabela seguida do seu número de ordem. Na figura, a fonte (Fonte:) vem sobre a legenda, à direta e sem ponto-final; na tabela, na parte inferior e com ponto-final. As figuras deverão estar exclusivamente em tons de cinza e, no caso de coloridas, será cobrada a importância de R$100,00/página.

O Manuscrito em PORTUGUÊS deverá seguir a seguinte seqüência: TÍTULO em português, RESUMO (seguido de Palavras-chave), TÍTULO DO MANUSCRITO em inglês, ABSTRACT (seguido de keywords); 1. INTRODUÇÃO (incluindo revisão de literatura); 2. MATERIAL E MÉTODOS; 3. RESULTADOS; 4. DISCUSSÃO; 5. CONCLUSÃO; 6. AGRADECIMENTOS (se for o caso); e 7. REFERÊNCIAS, alinhadas à esquerda.

O Manuscrito em INGLÊS deverá seguir a seguinte seqüência: TÍTULO em inglês; ABSTRACT (seguido de Keywords); TÍTULO DO MANUSCRITO em português; RESUMO (seguido de Palavras-chave); 1. INTRODUCTION (incluindo revisão de literatura); 2. MATERIAL AND METHODS; 3. RESULTS; 4. DISCUSSION; 5. CONCLUSIONS; 6. ACKNOWLEDGEMENTS (se for o caso); e 7. REFERENCES.

O Manuscrito em ESPANHOL deverá seguir a seguinte seqüência: TÍTULO em espanhol; RESUMEN (seguido de Palabra-llave), TÍTULO do Manuscrito em português, RESUMO em português (seguido de palavras-chave); 1. INTRODUCCTIÓN (incluindo revisão de literatura); 2. MATERIALES Y METODOS; 3. RESULTADOS; 4. DISCUSIÓNES; 5. CONCLUSIONES; 6. RECONOCIMIENTO (se for o caso); e 7. REFERENCIAS.

No texto, a citação de referências bibliográficas deverá ser feita da seguinte forma: colocar o sobrenome do autor citado com apenas a primeira letra maiúscula, seguido do ano entre parênteses, quando o autor fizer parte do texto. Quando o autor não fizer parte do texto, colocar, entre parênteses, o sobrenome, em maiúsculas, seguido do ano separado por vírgula. As referências bibliográficas utilizadas deverão ser preferencialmente de periódicos nacionais ou internacionais de níveis A/B do Qualis. A Revista Árvore adota as normas vigentes da ABNT 2002 - NBR 6023.

Não se usa "et al." em itálico e o "&" deverá ser substituído pelo "e" entre os autores.

A estrutura dos artigos originais de pesquisa é a convencional: Introdução, Métodos, Resultados e Discussão, embora outros formatos possam ser aceitos. A Introdução deve ser curta, definindo o problema estudado, sintetizando sua importância e destacando as lacunas do conhecimento ("estado da arte") que serão abordadas no artigo. Os Métodos empregados a população estudada, a fonte de dados e critérios de seleção, dentre outros, devem ser descritos de forma compreensiva e completa, mas sem prolixidade. A seção de Resultados devem se limitar a descrever os resultados encontrados sem incluir interpretações/comparações. O texto deve complementar e não repetir o que está descrito em tabelas e figuras. Devem ser separados da Discussão. A Discussão deve começar apreciando as limitações do estudo (quando for o caso), seguida da comparação com a literatura e da interpretação dos autores, extraindo as conclusões e indicando os caminhos para novas pesquisas.

O resumo deverá ser do tipo informativo, expondo os pontos relevantes do texto relacionados com os objetivos, a metodologia, os resultados e as conclusões, devendo ser compostos de uma seqüência corrente de frases e conter, no máximo, 250 palavras. (ABNT-6028).

2. Oecologia

Manuscript contents (in order)

Title page: should be concise and informative and less than 200 characters. Short titles (< 15 words) are best and are more often cited. The concept, problem or hypothesis to be tested should be clear from the title. The use of full taxonomic names in the title is discouraged; no taxonomic authorities should appear in titles.

Abstract: should include the following elements: introduction, hypothesis/objective, methods, results, conclusions and significance. It should not exceed 250 words in length. Each component should be restricted in length to 1-3 sentences. Allocate the greatest number of words to the results (~ 3 sentences) and less to each of the other sections (~1 sentence each). Include key quantitative data in the results.

Key words: Five key words should be supplied, indicating the scope of the paper and not repeating terms already used in the title.

Introduction

Materials and methods: Some submissions, such as reviews, may depart from the typical format of Methods-Results-Discussion.

Results: Avoid "Results are shown in Figure 3". Instead, say for example, "Biodiversity declined with the addition of nitrogen (Fig. 3)." Be specific: e.g., "positively correlated" instead of "correlated". Refer to magnitudes of effects (e.g. give effect sizes and confidence intervals) rather than just P-values.

Discussion; Acknowledgements; References: Literature citations in the text should be ordered chronologically and indicate the author's surname with the year of publication in parentheses, e.g. Carlin (1992); Brooks and Carlin (1992). If there are more than two authors, only the first author should be named, followed by "et al." For example, “Carlin (1992), Brooks and Carlin (2004, 2005), Jones et al. (2007) demonstrated…” OR “… well studied (Carlin 1992; Brooks and Carlin 2004, 2005; Jones et al. 2007)”. References at the end of the paper should be listed in alphabetical order by the first author's name. If there is more than one work by the same author or team of authors in the same year, a, b, etc. is added to the year both in the text and in the list of references.

References should only include works that are cited in the text and that have been published or accepted for publication. Personal communications and unpublished works should only be mentioned in the text. Alphabetize the list of references by the last names of the first author of each work. If available, the Digital Object Identifier (DOI) of the cited literature should be added at the end of each reference. Always use the standard abbreviation of a journal‟s name according to the ISSN List of Title Word Abbreviations (www.issn.org/2-22661-LTWA-online.php). Reference examples:

Journal papers: name(s) and initial(s) of all authors; year; full title; journal title abbreviated in accordance with international practice; volume number; first and last page numbers

Savidge WB, Blair NE (2004) Patterns of intramolecular carbon isotopic heterogenity within amino acids of autotrophs and heterotrophs. Oecologia 139:178-189 doi: 10.1007/s00442-004-1500-z

Chapter in a book:

name(s) and initial(s) of all authors; year; title of article; editor(s); title of book; edition; volume number; publisher; place of publication; page numbers

Hobson KA (2003) Making migratory connections with stable isotopes. In: Berthold P, Gwinner E, Sonnenschein E (eds) Avian migration. Springer, Berlin, pp 379-391

Book:

name and initial(s) of all authors; year; title; edition; publisher; place of publication

Körner C (2003) Alpine plant life, 2nd edn. Springer, Berlin

Tables: Each table should be submitted on a separate page, with the title (heading) above the table. Tables should be understandable without reference to the manuscript text. Restrict your use of tables to essential material. All tables must be cited in the manuscript text and numbered consecutively with Arabic numerals. Provide dimensions or units for all numbers. Identify any previously published material by giving the original source in the form of a reference at the end of the table heading. Tables will be printed with horizontal separation lines only (one below the table‟s header, one below the column headers, and one at the end of the table); no vertical lines will be printed. Use tab stops to align columns and center numbers around decimals when appropriate. Footnotes to tables should be indicated by superscript lower-case letters (or asterisks for significance values and other statistical data). The number of decimals presented should be sensible and match the precision of the data. Acceptable file formats for tables include Microsoft Word (.doc), Rich Text Format (.rtf) and Excel (.xls).

Figure legends: All figure legends (captions) should be assembled onto a separate page(s) preceding the figures. Each caption should be brief but sufficient to explain the figure without reference to the text.