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MORPHOPHYSIOLOGICAL RESPONSE OF *KHAYA SENEGALENSIS* A. JUSS IN LUMINOSITY LEVELS

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Abstract: For a good development of species with great economic value such as: *Khaya senegalensis*, which is exotic in Brazil, it is necessary analyzes of intrinsic characteristics to obtain responses of good adaptation to edaphoclimatic conditions in various regions of the country. Thus, the objective of this work was to investigate morphophysiological responses of seedlings of *Khaya senegalensis* under luminosity levels. An experiment was set up in the forest nursery at "Universidade Federal do Tocantins", distributed in a completely randomized design, divided into five treatments in luminosity levels (full sun, 70, 50, 30% and Natural Shade). Over the months, physiological measurements were taken (Assimilation of CO_2, Transpiration and stomatal conductance) and morphological (Height and DBH) with intervals of 30 days. At the end of the experiment, the total biomass and mass fractions (leaf, stem, root and total) were obtained. With that, there were significant results among the treatments tested for the species: *Khaya senegalensis*, because the levels of luminosity influenced the development of the seedlings, which obtained the highest growth rates in plants under partial levels (70, 50 and 30%) of luminosity. And also the physiological responses such as photosynthesis, transpiration and stomatal conductance were higher in high luminosity levels. That said, for the best initial development of the species: *Khaya senegalensis* regarding luminosity, it was evident that the partial levels (70, 50, 30%) favored the growth and quality of the seedlings, but the low level of light that arrives in the natural shade was not enough to guarantee the vigor of the African mahogany seedlings.
Keywords: African mahogany; photosynthesis; biomass.

INTRODUCTION

Khaya senegalensis is a species of African origin, which has desirable characteristics such as fast and straight growth and noble wood, being considered of excellent quality and can be planted in regions with prolonged drought (PINHEIRO et al., 2011). It is heliophytic, semi-deciduous, reaching 10 to 30 m in height (ORWA et al., 2009). Attack Resistant: *Hypsiphyla grandella*, main pest by which it made unfeasible plantations of *Swietenia macrophylla* in Brazil (LUNZ et al., 2009). In addition to the quality of the wood, its bark extract is used for the prevention and treatment of various diseases (OFORI et al., 2011).

Because it presents such characteristics, African Mahogany, more specifically the genus Khaya, has been increasingly highlighted in reforestation plantations or production plantations and in values in the forestry market, surpassing other exotic species such as Australian Cedar, Pinus, Eucalyptus and Teak (SOUZA, 2013).

And for monitoring the development of the species in the seedling and field stages in different climatic regions of Brazil, it is necessary to evaluate and understand the interaction of some factors such as: available nutrients, light, water, carbon dioxide and continuous flow of mineral salts, among others, which are responsible for the gain in plant biomass (LOPES and LIMA, 2015). The light on the plant directly interferes with the capacity photosynthesis, which is the process in which the fixation of carbon used in plant metabolism occurs (LARCHER, 2006). The activity of the photosynthetic apparatus changes according to the availability of light, causing the light compensation point to be higher in leaves that are in full sun conditions compared to those in shade (TAIZ and ZEIGER, 2013).

According to Gonçalves et al. (2012), acclimatization to different light regimes is a desirable characteristic for choosing species in reforestation programs or production plantations, since the irradiance that reaches the environment, or the different strata of the forest environment, is temporally and spatially heterogeneous. Thus, photosynthetically active radiation and dry matter production, related to the amount of light absorbed, have been used to define the efficiency of radiation use by plants (COSTA et al., 1996).

To obtain responses from some species regarding light tolerance, studies are carried out, providing consistent data on the tolerance of forest species to different light regimes and their ecological succession (LIMA et. al, 2010). The light tolerance of forest species is associated with their classification into ecophysiological groups. The species were classified according to the successional stage in pioneers, early and late secondary and climax (Budowski, 1965).

Some studies were evidenced by scientific research in responses to light variation, in the initial development of forest species such as: ''pau de balsa" (*Ochroma pyramidale*) (CUNHA et al,. 2016); ''copaíba" (*Copaifera langsdorffii*) (REIS et al., 2016); ''pimenta-rosa" (*Schinus terebinthifolius*) (SCHWANTES et al., 2015); ''pau ferro" (*Caesalpinia ferrea*) (LENHARD et al., 2013); ''angico" (*Anadenanthera falcata*) (MOTA et al., 2013), between others. However, here in Brazil, few results are found in ecophysiological studies with the species:*Khaya senegalensis*, mainly in response to variations in luminosity levels.

Thus, research with the species: *Khaya senegalensis* involving morphophysiological aspects in relation to luminosity levels are important for introduction and adaptation in different climatic regions of reforestation, aiming at restoration and/or forest production. Indeed, the objective of the present work was to evaluate the initial growth and the responses of the photosynthetic apparatus of *Khaya senegalensis* subjected to luminosity levels.

MATERIAL AND METHODS

The work was carried out in the experimental area of the Forest Nursery of "Universidade Federal do Tocantins" (UFT), University Campus of Gurupi, located in the southern region of the State of Tocantins, at 280 m altitude, at coordinates 11°43'45" of latitude and 49°04'07" longitude, from November 2015 to May 2016. The regional climate is humid with moderate water deficit (Köppen, 1948).

The seeds of *Khaya senegalensis* used for the production of seedlings were purchased from a private company and imported from Burkina Faso - West Africa. Disinfestation was performed according to recommendations by Dias et al., (2012). After disinfestation, the seeds were placed directly in beds containing washed sand, located in an area with a black polyethylene screen at 50% light and maintained under daily irrigation (BRASIL, 2009).

After germinating and reaching a pair of leaves, the seedlings were transplanted into polyethylene bags measuring 20 x 30cm (ALVES, 2013), containing 3.8 liters of substrate composed of subsoil soil from the 20 - 30 cm layer of an Oxisol Red Yellow medium texture, charred rice husk, washed sand and commercial substrate: *PlantFlorest®* in the proportion 2:1:1:1. Chemical and textural analyzes of the substrate were performed (Table 1), according to Miyazawa et al., (1999).

To ensure that the roots were fixed in the substrate, a period of fifty days was allowed after transplanting the seedlings into the bags and then they were selected according to the number of leaves, height and plant health, avoiding heterogeneity. The experiment was conducted in a completely randomized design (DIC), with five treatments and 8 replications. The seedlings were distributed in levels of luminosity, being 100% luminosity (full sun); 70% Luminosity (Sombrite); 50% Luminosity (Sombrite); 30% Brightness (Shade) and Natural Shade (1% Brightness).

In the treatment with natural shade, the seedlings were placed under a remaining area of native vegetation of savannah stricto sensu inside the University campus of Gurupi - TO, while the other levels of luminosity were obtained with black nylon screens (Sombrite), in structures assembled, wood and steel wires located in the UFT forestry nursery. The seedlings were allocated equidistant to 0.25 meters and irrigations were performed twice a day during the experimental period, always close to the water retention capacity of the substrate.

For the luminosity treatments, the irradiance values were determined, extracted from 10 punctual averages in each environment, (values recorded in the period from 11:00 am to 1:00 pm, without clouds) using a digital luxmeter Model LX- 1010BS, Brand Lux Tester. Such measurements were converted from lux to μmol photons m-2s-1 (Table 2) according to Thimijan and Heins, (1983).

Height and diameter measurements were taken at the beginning and at the end of the 150 days of experimentation. Quantitative analysis of plant growth was carried out from the absolute growth rates (ACT) in height and diameter, calculated by the difference between the readings at the end and at the beginning and divided by the months in which the experiment was carried out (Benincasa, 2003).

At the end of the experimental period, the substrate was removed and the root system was cleaned with water under low pressure, subdividing the plant into parts (leaves, stems and roots). The number of Leaves (NF): obtained through direct counting of the leaves;

pH $CaCl_2$	H+AL	Al	Ca	Mg	T	t	SB	K	P	Fe	Cu	Mn	Zn	B
	$cmol_c\,dm^{-3}$							mg dm^{-3}						
5,6	2,00	0	3,1	1,2	6,75	4,75	4,75	175	398,7	15	0,3	4,4	1,1	0,1

M.O	C.O	V	Argila	Silte	Areia
%			$g.kg^{-1}$		
1,9%	1,1	70	185	50	465

Table 1. Chemical and physical characteristics of the substrate used.

Treatments	Irradiance (μmol photons $m^{-2}s^{-1}$)
Full sun (100%)	2089 ± 74
70% of luminosity	1462 ± 63
50% of luminosity	1044 ± 47
30% of luminosity	626 ± 65
Natural shade (1%)	27 ± 5

Table 2: Percentage of luminosity and irradiance levels for treatments with the species: *Khaya senegalensis.*

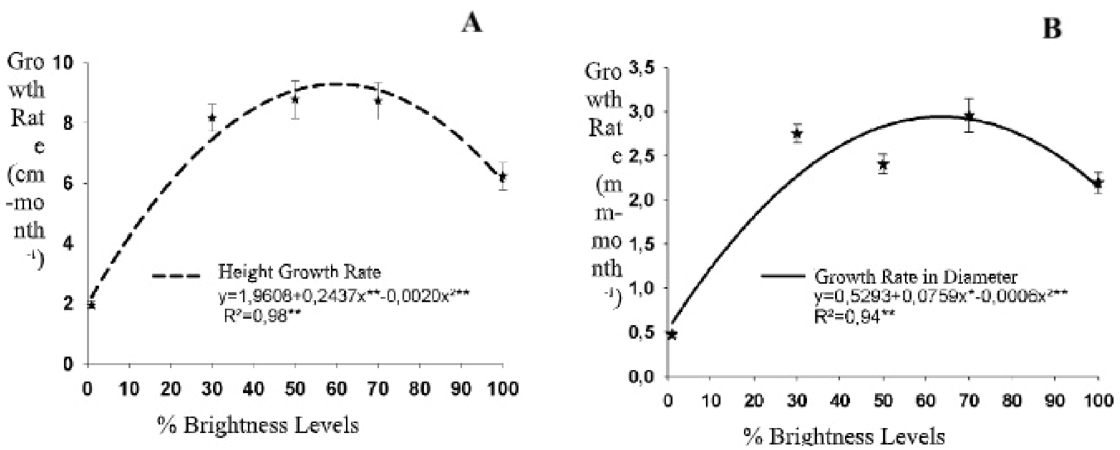

Figure 1: Absolute growth rate in height (cm-month^{-1}) and absolute growth rate in diameter (mm-month^{-1}) da *Khaya senegalensis* in brightness levels.

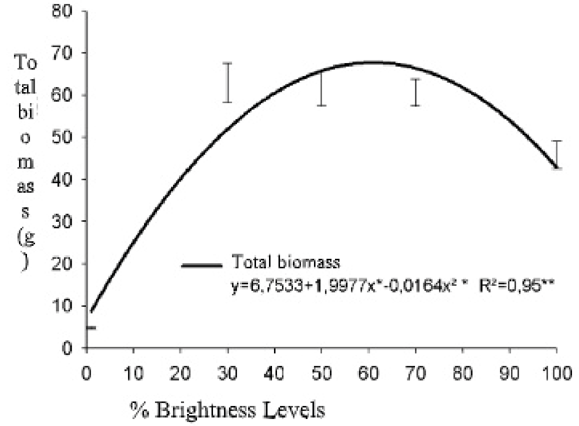

Figure 2: Biomass total of *khaya senegalensis* in brightness levels.

Leaf area (AF): determined using the LI-COR® Area Meter, model LI 3100 (all the leaflets of a plant were passed through the device one by one and later separated for drying) and the Specific Leaf Area (AFE): calculated from the ratio between leaf area and leaf mass of a single leaf (photosynthetically active area) completely expanded from the upper middle third of the plant (LOPES and LIMA, 2015).

For the determination of dry biomass, an oven with forced air circulation was used, at 65ºC for 72 hours, until constant mass was obtained (GOMES and PAIVA, 2011), weighed on an electronic analytical balance (0.0001 g), obtaining total dry mass (MST), leaf mass fraction (FMF= MSF/MST), stem mass fraction (FMC = MSC/MST) and root mass fraction (FMR = MSR/MST), (BENINCASA, 2003).

To carry out the physiological analyzes over the five months, a response curve of photosynthesis for the species was performed on the 30th day of the experiment in seedlings kept in full sun: *Khaya senegalensis*, to obtain maximum assimilation of CO_2 depending on levels of irradiance in the initial stage. This procedure was processed considering a photon flux density (PPFD) between 0 and 2000 μmol m-^{2} s^{-1} (0, 25, 50, 100, 250, 500, 800, 1000, 1200, 1500, 1800 and 2000) on a decreasing scale.

For response curve to increasing levels of species irradiance: *Khaya senegalensis*, at 30 days in full sun conditions, was expressed in an exponentially positive response of maximum assimilation of 7,58 μmol m^{2} s^{-1}. Based on this photosynthesis response curve for each species, artificial irradiance of 1500μmol m-^{2} s^{-1}, for carrying out the evaluations during the 150 days of experimentation.

At intervals of 30 days, the physiological analyzes occurred simultaneously in each plant, such as Assimilation of CO_2 (A), stomatal conductance (gs) and transpiration (E), with a portable open-system infrared gas analyzer (IRGA), model LI 6400 (Li-Cor, USA) equipped with an artificial light source, which was adjusted to work with flow of air 500 μmol s^{-1}, artificial radiation of 1500 μmol photons m^{-2} s^{-1}, concentrations of CO_2 and H_2O inside the measuring chamber around 380±1 μmol mol^{-1} and 28±1 μmol mol^{-1}, respectively (SANTOS JR. et al., 2013). Physiological measurements were always carried out in the upper middle third of the plant, in the leaflet of a completely expanded leaf in good phytosanitary condition, in the period between 09:00 and 12:00.

The data were subjected to a normality test, subsequently submitted to analysis of variance (ANOVA) and in the case of significant effects by the F test, regression was used to adjust models based on the significance of the coefficients at 1 and 5% of probability. All analyzes were processed using the Assitat 7.7 software (SILVA, 2016) and the regression graphs were plotted using the statistical program SigmaPlot version 10.0 (MELO, 1993).

RESULTS AND DISCUSSION

It was observed that the plants of *Khaya senegalensis* conditioned in partial luminosity environments with 70%, 50% and 30% and presented absolute growth rates in height of 8,73; 8,88 and 8,17 cm month^{-1}, not statistically different between these treatments. These growth rates of plants in the partial light condition were higher than the growth rates of plants exposed to full sun and natural shade, with:6,24 cm month^{-1} and 1,95 cm month^{-1}, respectively (Figure 1A). The evaluation of growth represents the first step to interpret the primary production of the plant mass, it is a simple and easy method to be used, indicating in this study that for the greater development of the species, the luminous environment needs to be in the range of 600 to 1500 μmol

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photonsm^{-2}s^{-1}.

For *Khaya senegalensis,* the absolute growth rate in height showed a non-linear response, with adjustment of the equation in the quadratic function, indicating a maximum point in the curve of 60% of luminosity, that is, the ideal for the initial growth of the species revolves around this percentage (Figure 1A). And Cunha et al., (2016), evaluating irradiance levels in another commercial forest species (*Ochroma pyramidale*), found results in the absolute height growth rate with the species of 4,61 cm month^{-1} under conditions of irradiance at 1200 to 1400 μmol photons: m^{-2}s^{-1}.

The morphological response observed in the regression curve in plants of: *Khaya senegalensis* for the absolute growth rate in diameter, the growth response in height was similar, in adjustment in the equation with a quadratic function in the curve, reaching the maximum point of 63% of luminosity. The absolute growth rate in diameter ranged from 0,47 to 2,95 mm month^{-1} (Figure 1B), this result represents the average speed of growth of the species over time and showing the highest growth rate in plant diameter, in the treatment with 70% luminosity (1500 μmol m^{2} s^{-1}) with 2,95 mm month^{-1} (LOPES e LIMA, 2015).

Observing the absolute growth rates for the species, it was noticed that plants, when submitted to a low level of irradiance, presented lower values of growth both in height and in diameter (Figure 1A and 1B). Generally, morphological analyzes (height and diameter) of growth in the initial development of species are used to predict the level of tolerance to different irradiances, which can be related to the capacity of the plant to grow and the efficiency of adaptation to the environmental conditions that the plant itself is found. Based on this, it was observed that the response of low growth, expressed that the species did not have adaptive capacity for habitat conditions with intense shade, which tended to present a slower growth, confirming its classification to the initial secondary ecological group that it is inserted, that is, the ecological classification, regarding the light requirement in the successional stage (PINHEIRO, 2011).

For the accumulation of total biomass of the species, significant differences were evidenced (Figure 2) between the full sun (45.75 g) and natural shade (4.84 g) treatments. The highest biomasses were found in plants under partial irradiance conditions (70, 50 and 30% of luminosity) with 62.92; 61.55 and 60.56 g respectively, characterizing the accumulation of biomass in growth and greater development under these conditions.

For *khaya senegalensis, a* fit was found with a quadratic polynomial equation and the maximum point was obtained for biomass at 60% luminosity. This fact confirms the answer of the species: *khaya senegalensis,* in the secondary ecological succession group. According to Pinheiro (2011), the species of the genus: *Khaya* are classified as moderately shade tolerant, for example: secondary.

Secondary species are heliophilous, characterized by species that establish and grow under canopy, but require clearings to mature and reproduce (MACIEL et al., 2003). Gonçalves et al., (2012), worked with the species: *Swietenia macrophylla* obtained a greater result in the accumulation of biomass in plants with high luminosity compared to natural shade with low levels of luminosity.

For the species distribution in fractions of leaf, stem and root mass, it was noted that there was a homogeneous partition in plants in full sun, with values closer to each other (Figure 3A), gradually differing according to the luminosity levels. The trends of the curves as a function of luminosity levels showed opposite responses to each other, increasing linearly for leaf mass fraction and decreasing linearly for root mass, expressing a storage of photoassimilates in the roots of shade plants.

Comparing the leaf mass fraction for the species, it was noted that the maximum light point was around 50% (Figure 3A). These mass partitions demonstrated the response of the plant regarding the availability of light and storage of assimilates, which reflect on the growth of the species. The species: *Khaya senegalensis* showed lower mass accumulation in plants in natural shade and Roweder et al., (2011), recorded a higher value for root mass in 50% shading for seedlings of *Cedrela odorata*, when compared to sun plants.

The number of leaves for the species showed a response with quadratic functions, with a maximum point of 57% of luminosity (Figure 3B). The number of leaves represents the investment in structures to capture more solar radiation, in the present study it was revealed that the partial luminosity levels (70, 50 and 30%) were higher. Similar results were found by LIMA et al. (2010), with species: *Hymenaea courbaril*, submitted to luminosity levels, presented larger numbers of leaves in plants of partial luminosity levels.

The total leaf area for the species showed significant differences between treatments, with a quadratic polynomial expression and maximum point of 56% light (Figure 4A). It was noted that for plants exposed to full sun, their size was 92% smaller than plants with 50% luminosity. Larcher (2006) reports that by expanding the leaf area, the plant's ability to use radiation photosynthetically increases, showing the response and ability of the species to different environments. Similar results were found by Silva and Dantas (2014), with species: *Sideroxylon obtusifolium* in conditions of partial luminosity levels.

And for leaf area for the specific species, the opposite occurred in plants kept under low light, showing higher specific leaf area values (Figure 4B). Similar results were found by Siebeneichler et al., (2008), with species: *Tabebuia heptapylla*, indicating an adaptation of the species to these light conditions. This parameter represents how much the plants in low light conditions were able to adapt to the environment, showing tolerance and ensuring survival during a period of time under a shaded canopy, expressing the adaptive capacity with the increase of the leaf in area and not in leaf content, as a strategy to capture the highest energy in the flow of photosynthetically active photons (TAIZ and ZEIGER, 2013). Even managing to survive in this environment, the leaflets of plants in natural shade developed less, demonstrating a smaller number of leaflets (Figure 5).

For the species: *Khaya senegalensis,* the results of the net assimilation rate of CO_2 between treatments luminosity levels and over time varied between treatments, differing statistically between plants kept in low light and plants in higher luminosity levels (Figure 6). This indicates that there was high photosynthetic activity in full sun, as well as in plants kept at partial luminosity levels (70, 50 and 30%), as the physiological responses were better in these partial light conditions. It was observed that the photosynthetic activity varied over time within the same treatment, that is, showing that even the plants maintained at specific luminosity levels conditions, there were different responses, due to climatic variations. Authors Lopes and Lima (2015) report that the photosynthetic process involves many factors, such as relative humidity, availability of nutrients, wind, water, concentration of CO_2 in the atmosphere, luminosity, among others, making the assimilation of CO_2 is modified.

The variation of the CO2 assimilation rate found in the species: *Khaya senegalensis* (from 2 to 9 mmol fótons m^2s^{-1}), (Figure 6) can occur in woody species of tropical climate regions, and can vary in photosynthetic rate by 6 to

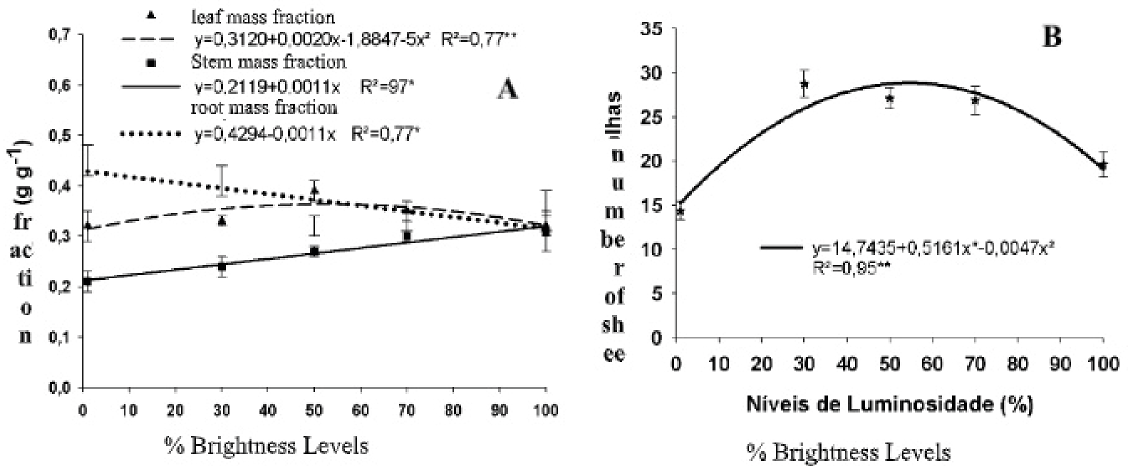

Figure 3: Leaf, stem and root mass fractions (A) and number of leaves (B) of *khaya senegalensis* according to luminosity levels.

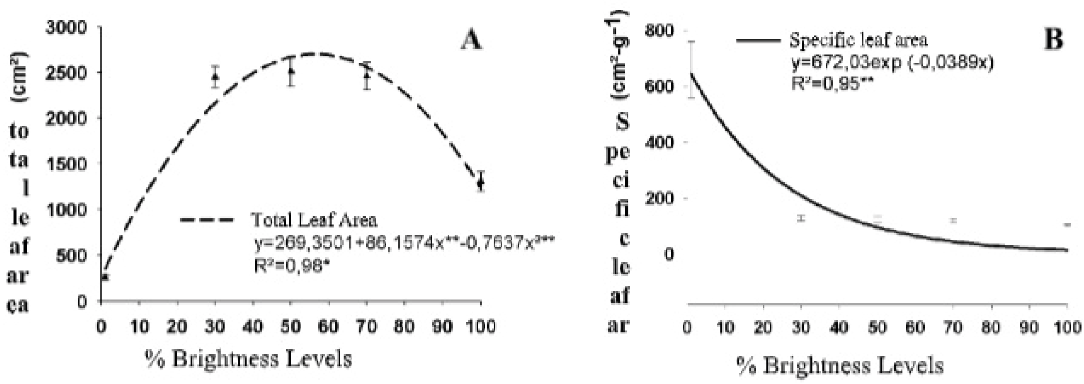

Figure 4: (A) Total Leaf Area (cm^2) and (B) Specific leaf area ($cm^2\ g^{-1}$) of *khaya senegalensis,* according to luminosity levels.

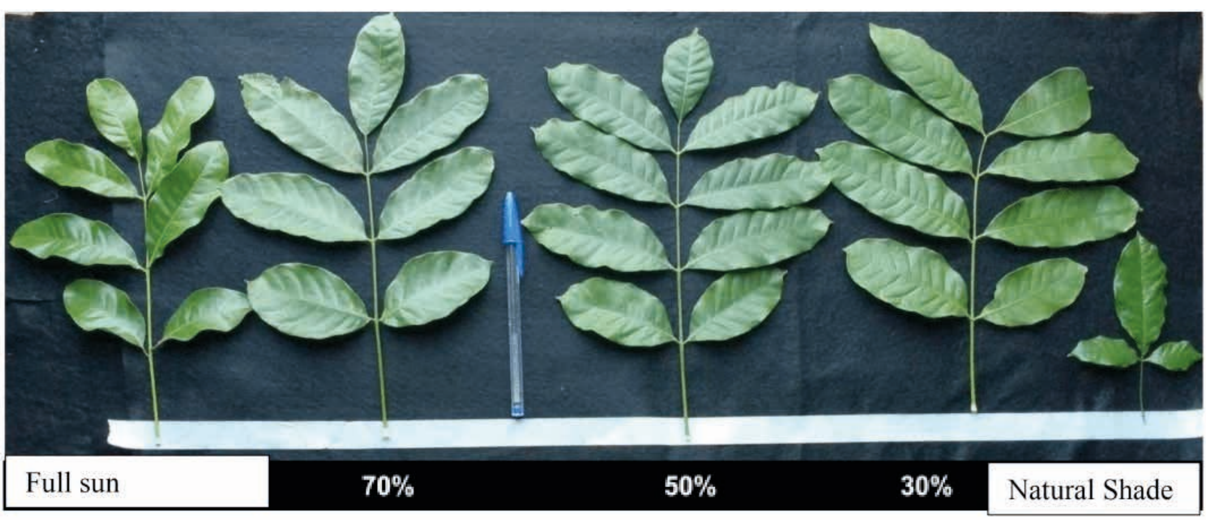

Figure 5: Leaves of *Khaya senegalensis* according to luminosity levels after 150 days of evaluations.

15µmol fótons m^2s^{-1}. For the species: *Swietenia macrophylla* (Brazilian mahogany), Gonçalves et al., (2012), found a light saturation of 5.41µmol fótons m^2 s^{-1} in full sun plants. The light saturation rate is when the plant cannot absorb more photons of light, corresponding to the maximum and thereafter becomes constant (TAIZ and ZEIGER, 2013).

For the species: *Khaya senegalensis* in the environmental conditions of the present study, of luminosity levels, there was a higher rate of assimilation of CO_2 between the months of February and March, according to the curves shown for plants exposed to full sun and partial luminosity (70, 50 and 30%) (Figure 6).

This fact may have occurred due to the environmental conditions varying over time in the experiment site, since only the luminosity levels were controlled. Lower rates (2.16 to 4.00 µmol photons m^2 s^{-1}) of assimilation of CO_2 occurred in plants in natural shade (Figure 6), due to the low photosynthetically active radiation, however, in this treatment the trend curve was linear over time, showing that in the months of April and May they were higher. Similar results were found by Mendes (2009) with tree species, analyzing physiological responses in different seasonality throughout the year in Central Amazonia.

Mota et al., (2009), analyzing luminosity levels with the species: *Anadenanthera falcata* obtained higher rates of photosynthesis in environments with higher irradiance when compared to other treatments. These low luminosity levels results for species: *Khaya senegalensis* confirm the low accumulation of total biomass (Figure 2), the low growth rate (Figure 1), due to the low photosynthetic activity of plants allocated in natural shade, (Figure 6).

How much is stomatal conductance for *Khaya senegalensis,* it was observed that the results were similar to those found in the response of the CO2 assimilation rates (Figure 6), with quadratic functions for the luminosity levels over time, showing the highest rates in the months of February and March (Figure 7).

The values of stomatal conductance rates for: *Khaya senegalensis* varied from 0,08 to 0,78 mmol m^2 s^{-1}, across levels and over time (Figure 7). Vieira et al., (2011) working with the species:*Cariniana legalis* under variations in light conditions and acclimatization capacity, variation in stomatal conductance rates was observed. The stomatal opening is directly linked to the regulation of gas exchange and transpiration, through the variation in the stomatal opening it is possible to control the flow of CO2 and water in the leaf (DIAS and MARENCO, 2007).

For *Khaya senegalensis,* the transpiration rate had a varied response over the evaluation period, it was noted that the plants in natural shade had a linear adjustment as a function of time, over the evaluation period (Figure 8). Possibly, in natural shade, the microclimate is milder in terms of leaf temperature, consequently a lower transpiration flow, compared to plants in full sun. Over time, the highest rates for the natural shade treatment were in the month of May, with an increasing linear adjustment. This fact may be related to the time of year, the end of the month of May (Figure 1), the climate in the southern region of the State of Tocantins changes, with constant winds, lower relative humidity and lack of precipitation, requiring greater transpiration flows.

For the species, the results in plant transpiration in treatments with higher levels of irradiance in an area of full sun showed transpiration fluxes 3.13 to 5,79 mmol m^2s^{-1} (Figure 8), demanding greater efficiencies in the root system for water absorption and plant cooling. The highest transpiration rates are linked to the opening and closing of the stomata, since the absorption of CO_2 from the

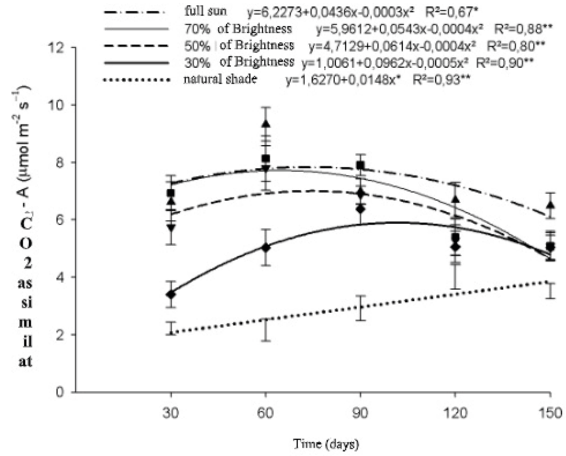

Figure 6: Assimilation rate of CO_2 as a function of irradiance levels and over time in young plants of: *Khaya senegalensis.*

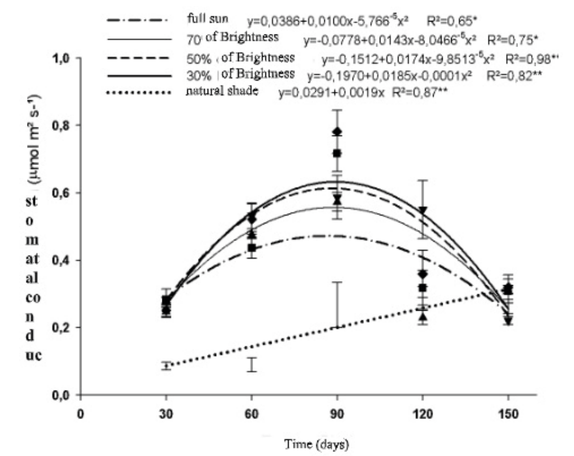

Figure 7: Stomatal conductance as a function of irradiance levels and over time in young plants of *Khaya senegalensis.*

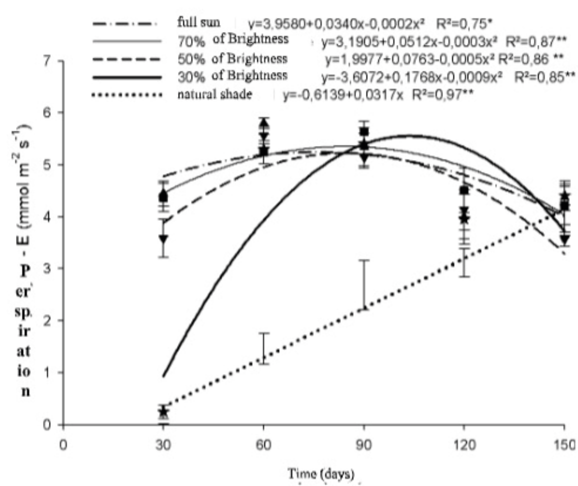

Figure 8: Leaf transpiration as a function of irradiance levels and over time in young plants of *Khaya senegalensis.*

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external environment and the loss of water in the form of steam are closely linked processes, so that the reduction of water loss also restricts the entry of CO2, since the stomata are the common entry and exit route for CO2 and water (TAIZ and ZEIGER, 2013).

Based on the morphophysiological results found in this work for the species *Khaya senegalensis,* the levels of luminosity provided different photosynthetic activities and consequently accumulation of biomass.

CONCLUSIONS

In the initial development of *Khaya senegalensis*, low luminosity affected photosynthetic activity, decreasing biomass accumulation and growth. In plants under luminosity conditions of 70% to 30% of luminosity, equivalent to irradiances between 1500 and 600 µmol photons m^2 s^{-1} showed absolute growth rates in height of 8.73; 8,88 e 8,17 cm $month^{-1}$, in the treatments presenting 70%, 50% and 30% respectively.

For the biomass accumulation fractions in the species: *Khaya senegalensis,* there was a homogeneous partition the distribution in leaf, stem and root mass fractions. The leaf analyzes of plants under natural shade conditions expressed a specific leaf area of 661,16 cm^2 g^{-1} in natural shade plants and 102,99 cm^2 g^{-1} in full sun plants, which expressed an adaptive way of capturing the light necessary for their survival.

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