WATER REQUIREMENTS OF *Dipteryx alata* VOGEL SEEDLINGS AT DIFFERENT SOLAR RADIATION LEVELS IN CERRADO-AMAZON TRANSITION †

[NECESIDADES HÍDRICAS DE MUDAS DE *Dipteryx alata* VOGEL EN DIFERENTES NIVELES DE RADIACIÓN SOLAR EN LA TRANSICIÓN CERRADO-AMAZON]

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SUMMARY

Background. Water and energy availability are factors that determine the maintenance, growth and development of plants and, consequently, affect its productivity. knowledge what water requirements of forest species during the initial growth stage under different energy levels are essential for technical and economic planning and the proper management of irrigation in forest nurseries, aiming at the production of healthy seedlings. **Objective.** The evapotranspiration potential (ETc) and crop coefficients (Kc) of baru plants (*Dipteryx alata* Vogel) were set at the early plant development stage, at increasing shading (black polyolefin screens) and spectral solar radiation levels (colored polyolefin screens), in order to subsidize irrigation and management projects focused on forest nurseries. **Methodology**. The experiment was conducted in the Center-Northern region of Mato Grosso State, during the dry season (from June to October 2017), for 125 days. ETc was measured through capillary lysimeters, whereas reference evapotranspiration (ETo) was set through the *FAO-56 Penman-Monteith equation* - Kc values were defined through the ETc/ETo ratio. Destructive growth analysis was performed 125 days after transplantation in order to determine the morphometric variables of the plants. **Results.** Increased shading levels decreased ETc, Kc and seedling stem diameter, besides increasing the leaf area. The herein adopted quantitative and spectral shading levels did not affect growth (in height) and dry mass accumulation in different *D. alata* seedling partitions. **Implications.** The results obtained allow defining improvements in the management of irrigation of forest nurseries. The adoption of irrigations systems with design errors and/or with water requirements inadequate for the production of forest seedlings may lead to yields lower than the genetic potential of the species, favor the establishment of diseases increased the consumption of nutrients and water. **Conclusion.**The production of *D. alata* seedlings depends on the cost-benefit ratio of shading screens and local water availability - production in full sun condition is recommended whenever water is not a limiting factor.
Keywords: Evapotranspiration potential; Crop coefficients; Irrigation management; Baru plant; Protected-cultivation screens.

RESUMEN

Antecedentes. La disponibilidad de agua y energía son factores que determinan el mantenimiento, el crecimiento y el desarrollo de las plantas y, en consecuencia, afectan su productividad. Conocer las necessidades hídricas de las especies forestales durante la etapa inicial de crecimiento bajo diferentes niveles de energía es esencial para la planificación técnica y económica y el manejo adecuado de riego en viveros forestales, con el objetivo de producir plántulas saludables. **Objetivo.** Para subsidiar proyectos y manejo de irrigación en viveros forestales, en la fase inicial de desarrollo inicial y en diferentes niveles de sombreado (pantolines poliegines negros y coloridos), se determinó la evapotranspiración potencial (ETc) y los coeficientes de cultivo (Kc) del baruzo (*Dipteryx alata* Vogel). **Metodología.** El experimento fue conducido en la estación seca, de la región Centro-Norte de Mato Grosso (junio a octubre de 2017), durante 125 días. La ETc fue obtenida por lisímetros de capilaridad y la evapotranspiración de referencia (ET_0) por el método de Penman-Montheit Fao 56, siendo los valores de Kc definidos por la razón ETc/ET_0. El análisis de crecimiento destructivo se realizó125 días después del transplante para determinar variables morfométricas de la planta. **Resultados.** El aumento del nivel de sombreado disminuyó la ETc, Kc y el diámetro del colecto de las mudas, y aumentó el área foliar. Los diferentes niveles de sombreado

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no afectaron el crecimiento en altura y la acumulación de masa seca de las diferentes particiones de las mudas. **Implicaciones.** Los resultados obtenidos permiten definir mejoras en el manejo del riego en viveros forestales. La adopción de sistemas de riego con errores y/o con gestiones de agua inadecuadas para la producción de plántulas forestales puede conducir a rendimientos inferiores al potencial genético de la especie, favorecer el establecimiento de enfermedades, aumentar el consumo de nutrientes y agua. **Conclusión.** La producción de mudas de *D. alata* depende de la relación costo-beneficio de las pantallas de sombreado y de la disponibilidad hídrica local, siendo que, cuando el agua no es un factor limitante, se recomienda la producción al pleno sol.
Palabras clave: Evapotranspiración potencial; Coeficientes de cultivo; Manejo de riego; Baru; Telatos de cultivo protegido.

INTRODUCTION

Urbanization, public policies and economic variables led to the occupation of different Brazilian regions, besides triggering accelerated growth and occupation processes that stimulated economic and social development based on the increased demand for natural resources such as products and by-products from native forest essences. However, this system benefits from the fact that intensified urbanization and forest-product exploration processes can influence the local/regional climate and directly, or indirectly, affect plant ecosystems.

The aforementioned scenario indicates decreased forest-product supply. Thus, it is necessary conducting ecophysiological studies about native and/or exotic plants with potential to be inserted in rational farming areas managed to meet the different uses and purposes given to forest products and by-products.

Accordingly, the success of forest plant-insertion programs depends on the species of choice, on the goals and, mainly, on the quality of seedlings at their initial development stage. Thus, besides resisting adverse conditions such as drought (Gordin et al., 2015), high insolation (Leal et al., 2015) and low soil fertility levels (Silva et al., 2016), wildfires, pests, diseases, among others, seedlings must be able to develop and show their full productive potential to meet the goals set for the crop site.

The successful implementation of rational forest-species farming in nurseries at the initial phase depends on producers' knowledge about the water requirements of each species at initial developmental stage. Such knowledge helps generating quality seedlings and increasing the water-use efficiency through proper planning and management of the adopted irrigation regime (Thebaldi et al., 2014; Monteiro et al., 2016).

Seedling production procedures, and the care given to the initial establishment of forest plants, are important instruments for ecological processes. However, the lack of ecophysiological information about species-specific requirements and silvicultural techniques adopted in such production processes has encouraged researchers to conduct innovative studies focused on generating more vigorous and adapted individuals. Abiotic factors such as water availability, air temperature, substrate type and light intensity, in combination with intra and intercellular control factors such as genetic potential and plant biochemical hormones, respectively, play a key role in the seedling-growth process.

The potential/attainable growth and development of forest seedlings is influenced by the correct replacement of the water moving in the soil (substrate) – plant - atmosphere system. The explanation for this dependence lies on the fact that water takes part in all biochemical, physicochemical and physiological plant reactions such as photosynthesis, hydrolytic reactions, breathing, turgescence maintenance, cell expansion, compound synthesis, mineral transport, thermoregulation, biomass accumulation and seed germination, among others (Gordin et al., 2015; Moura et al., 2016; Yin et al., 2016).

Therefore, solar radiation is a direct source of energy for processes such as photosynthesis and biomass accumulation. Each species has its own light-intensity, spectral quality and incident solar radiation requirements. The light requirements of species grown in protected farming environments can be assessed through artificial shading, since it enables even solar-radiation distribution and allows isolating and measuring the light effects on plants in order to help identifying the proper solar radiation levels for different developmental stages of the investigated species (Mota et al., 2012; Costa et al., 2015; Leal et al., 2015).

Dipteryx alata Vogel (baru plant) stands out among many forest species native to the Cerrado biome, and to Brazilian Cerrado-Amazon transition areas, since it has high economic, social and environmental potential. The species is mainly used to produce timber, food, cosmetics, medications, paper and cellulose, besides being applied to landscaping, production systems, pasture shading, as well as to the recovery and restoration of degraded areas (Bueno et al., 2013; Magalhães, 2014; Oliveira et al., 2017).

Given the added value of *D. alata* and the scarcity of information about the species' water requirements and early development under different environmental conditions, the aim of the current study was to investigate the evapotranspiration potential (ETc), crop coefficients (Kc) and the early development stage of *Dipteryx alata* Vogel under increasing and spectral solar radiation levels during the dry season in the Center-Northern region of Mato Grosso State.

MATERIALS AND METHODS

The experiment was conducted from June 4 to October 7, 2017 (125 days), in Sinop County - MT (latitude 11° 51' 50" S; longitude 55° 29' 08" W; altitude 384 m) (Figure 1). According to Köppen's classification, the region presents climate type Aw (tropical hot and humid), has two well-defined water seasons: rainy (October to April) and dry (May to September), besides recording mean monthly temperature ranging from 24 °C to 27 °C and 1970 mm annual rainfall (Souza et al., 2013).

Three hundred and twenty-four *D. alata* seedlings were grown in nine suspended modules, with thirty-six seedlings per nursery. These experimental modules were aligned to the East-West direction - dimensions 3.0 x 1.0 x 1.0 m (length, width and height) - 1.0 m above the soil with top, front and side coverings made of black and colored agricultural polyolefin screens, being for the black screens the commercial shading indications set at 35, 50, 65 and 80 % and for colored screens, the were evaluated the thermo-reflector (aluminet®), red and blue chromatinet, green frontinet, all with shading commercial indication of 50 %; besides the full sun (control) condition.

Meteorological variables (air temperature, relative air humidity, wind speed and rainfall) in the full sun condition were monitored by an Instrutemp automatic weather station (model ITWH-1080) placed 20 m away from the experimental area – data were stored every 30 minutes. Global radiation was measured based on insolation by using linear (a) and angular (b) coefficients regionally calibrated at monthly scale by Martim et al. (2014).

The daily reference evapotranspiration (ET_0) was measured through the FAO-56 Penman-Monteith method (Allen et al., 1998), based on meteorological measurements conducted in full sunlight, as recommended by Pereira et al. (2013) - variables of the model applied to humid climate regions were taken into consideration in this case.

The micrometeorological monitoring of temperature and relative air humidity in the shading screens was conducted at 30-minute intervals and carried out through thermo-hygrometers equipped with Instrutemp datalogger (model HT 4000 ICEL) installed 1.50 m above the ground in the center of each experimental nursery.

Global radiation (Hg), photosynthetically-active radiation (Hpar) and luminance (Lux) were measured through pyranometers (MP-200, MQ-200 - Instrutherm) and lucimeters (LD-200 - Instrutherm), respectively, in order to evaluate solar radiation attenuation through polyolefin screens. These sensors were fixed on a leveled metal platform (at 1.50 m inside the nursery and 0.50 m above it). Readings were performed fortnightly, between June and October, from 8:00 to 11:00 am (local solar time), outside (above) and inside the nurseries in order to find the attenuation and transmissivity (interior/exterior reading ratio) of the shading screens.

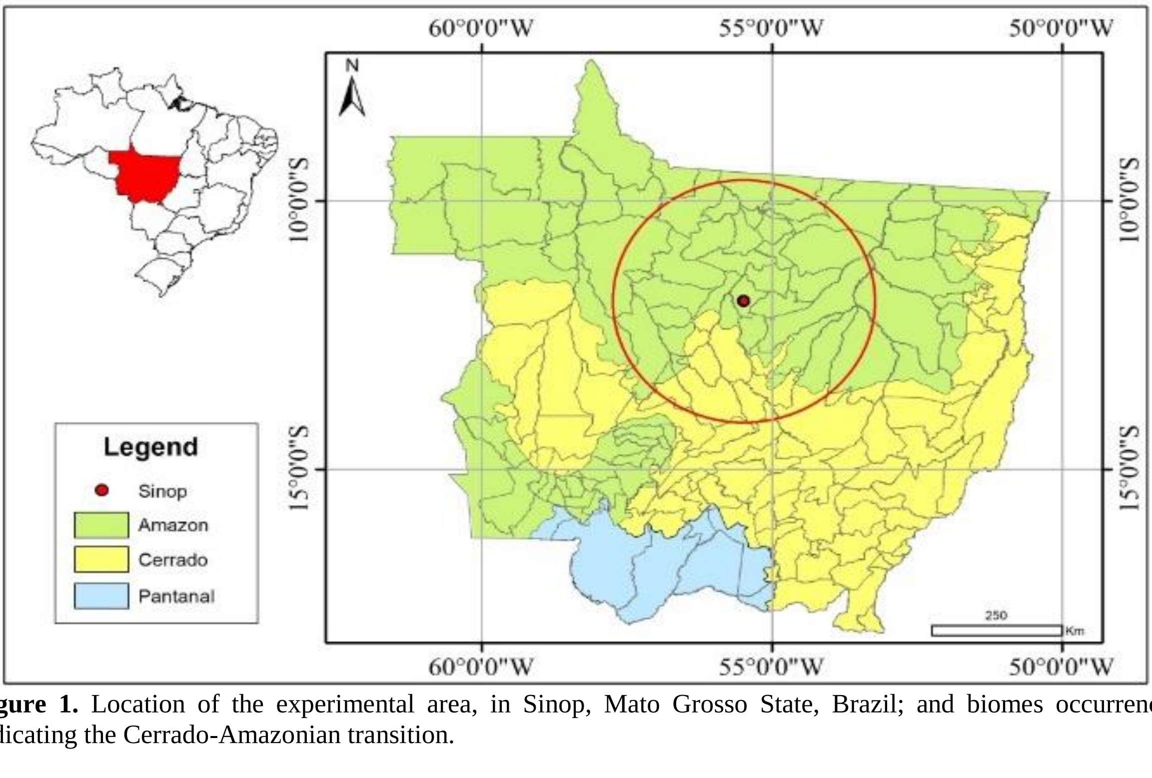

Figure 1. Location of the experimental area, in Sinop, Mato Grosso State, Brazil; and biomes occurrence, indicating the Cerrado-Amazonian transition.

Therefore, the mean Hg, Hpar and Lux transmissivity values recorded for the commercial black polyolefin screens were: 35 % (54.72 %, 53.25 % and 51.67 %); 50 % (45.91 %, 43.27 % and 43.36 %); 65 % (31.75 %, 33.34 % and 29.81 %) and 80 % (16.70 %, 15.49 % and 15.12 %); whereas the ones recorded for the colored screens were: 50% aluminet® (32.51 %, 35.25 % and 33.67 %), 50 % red chromatinet® (47.00 %, 30.95 % and 27.99 %), 50 % blue chromatinet® (44.35 %, 37.09 % and 33.17 %) and 50 % green frontinet® (39.35 %, 28.74 % and 29.72 %). These findings indicate differences between the commercial definitions of the screens and the actual attenuations recorded for H_G, H_{PAR} and Lux.

Baru fruits were collected in matrices located in Rondonópolis County - MT (latitude 16° 28' 03" S; longitude 54° 38' 49" W; altitude 287m) from August to September 2016. They were stored in raffia bags (in the shade) for eight months. Seed germination happened in a germination chamber at 30 °C, under 12-h photoperiod. Seeds were washed with 2 % sodium hypochlorite (NaClO) solution for 5 min and sprayed with 2.0 % Protreat® (fungicide solution) during germination on plastic trays wrapped in Germitest® paper moistened with distilled water.

Seedlings were transplanted to 820 cm³ black polyethylene tubes and kept under black screen (50 % Hg attenuation) for 30 days in order to enable sprout acclimation and uniformity. After the third fully-expanded compound leaf emerged, seedlings were distributed in the treatments for ETc evaluations.

The composition of the herein adopted substrate comprised 50 % organic matter (plants and animal residue), 10 % charcoal rice husk and 40 % native forest soil (Dystrophic Red-Yellow Latosol). Chemical fertilization was carried out with 40g N, 380g P_2O_5 and 80g K_2O (per m³ of soil), which were used in the form of urea, simple superphosphate and potassium chloride, respectively.

Water retention capacity of the substrate (WRCS) in 820 cm³ tubes (filled with approximately 700 grams of the aforementioned substrate) was measured through saturation, natural drainage, wet substrate weighing, drying at 105 ± 1.0 °C, dry-sample weighing until reaching constant mass. WRCS variations from 0.46 to 0.40 g of water per g of substrate and from 0.56 to 0.57 g cm^{-3} of substrate density were recorded at 0 and 125 days after transplanting (DAT), respectively.

The following morphometric seedling-growth variables were recorded at 125 DAT: seedling height; seedling stem diameter; number of leaves (NL) and leaflets (NLe) per seedling; leaf area of the seedling (measured with an LI-3100C photoelectric meter); root system length (RSL); root system volume (immersion in graduated test tube); root, stem, leaf and total dry masses (measured in analytical scale - 0.0001 g precision- after drying the plant material in forced air circulation oven at 65 °C ± 5 °C, until reaching constant mass). These evaluations took into consideration four repetitions of nine seedlings per treatment.

The daily ETc of baru seedlings was measured through capillary lysimeters, with four repetitions per treatment (shading screens and full sun). The lysimeters consisted of two polypropylene trays (16,500 cm³ and 3,300 cm³) connected to each other by a polyvinyl chloride tube (12.5 mm diameter) and sealed with thread-seal tape and adhesive paste. The larger tray housed nine baru seedlings in 820 cm³ tubes suspended between the base and the top of the tray. Spaces between tubes and the tray lid were sealed with antifungal silicone to prevent water loss caused by direct evaporation.

After capillary system was assembled and replicated (36 units), and the seedling were transplanted to the lysimeters, the trays were marked at different levels to allow daily evapotranspiration readings. The two trays (16.5 L and 3.3 L) were filled with 10.0 L and 1.0 L of water, respectively. The smallest tray worked as control tank and evapotranspiration in it was measured based on daily water replenishment up to the reference level (using a graduated test tube). The lysimeters were periodically cleaned to avoid algae proliferation and substrate deposition.

The substrate was left to stabilize the WRC for four days, after the transplantation procedure was over. Crop evapotranspiration (ETc) was measured from June 4 to September 27, 2017 (115 DAT), whereas crop coefficient (Kc) values were based on the ETc (in the shading screens)/reference evapotranspiration (ET_0) ratio under full sun condition.

ETc and Kc variations throughout the seedling development cycle were analyzed by taking into consideration the accumulated thermal sum (accumulated degree days - ADD) in order to enable applications regardless of the climate conditions in the crop area. In order to do so, the upper (UBT) and lower (LBT) basal temperatures of baru seedlings were based on polynomial regressions comprising the maximum and minimum air temperature (independent variables) in each treatment (shading screens) throughout the experimental period (125 DAT) and the total mean leaf area per seedling (dependent variable) in each treatment, at 125 DAT.

These correlations enabled finding significance for quadratic polynomials, which allowed setting 39.8 °C and 10.1 °C as UBT and LBT values, respectively. The accumulated thermal sums were based on the Ometto method, as recommended by Souza et al. (2011).

The statistical analyses were distributed according to the following shading screen groupings: quantitative analysis - to evaluate the effect of the increased shading level (full sun and black polyolefin screens - 45.3%, 54.1%, 68.3% and 83.3% shading); and qualitative analysis - to evaluate the spectral solar radiation effect (full sun, black screen (54.1%), thermo-reflective screen and colored polyolefin screens). The design was in randomized blocks and data were subjected to analysis of variance. Subsequently, the significant means were compared through the Tukey test, at 5 % probability level.

RESULTS AND DISCUSSION

The mean daily air temperature (Tair) during the experimental period under full sun, black polyolefin screen and thermo-reflective screen conditions was 26.0 ± 0.2 °C, whereas the red, blue and green screens recorded T_{air} values were 26.64 °C, 26.84 °C and 26.72 °C, respectively. The full sun condition recorded the lowest (55.79 %) mean daily relative humidity (RH), whereas the black screen (83.3 % shading) recorded the highest one (61.31 %). The other shading screens recorded approximately 60.0 % RH (Figure 2). Overall, the highest Tair and RH amplitudes were recorded between July and September: Tair was higher than 40 °C in August and lower than 10 °C in July, whereas RH was higher than 90 % in September and lower than 10 % in July, August and September.

The behavior of these meteorological elements in this period of the year mainly depend on the incidence of solar radiation. According to Souza et al. (2016), the Amazonian area in Mato Grosso State presents the highest atmospheric solar radiation-transmissivity rates during the dry season (mainly in August) due to low attenuation of solar radiation. Such radiation attenuation results of their interaction with atmospheric constituents such as clouds, water steams and aerosols.

The increased shading level decreased the incidence of total daily solar radiation (H_G) (Figure 2E). The colored screens recorded H_G oscillations from 5 to 12 MJ m^{-2} day^{-1}: shading with red, blue, black, green and thermo-reflective screens recorded high incidence of H_G oscillations (Figure 2F). The highest H_G levels were recorded in August, regardless of the shading condition. This outcome corroborated the studies by Souza et al. (2016) and Monteiro et al. (2016).

Plants grown under full sun condition recorded high H_G, insolation and ET_0 oscillation in August and September (Figures 2G and 2H). The low incidence of H_G during this period was associated with air mass displacements, which carried clouds towards the region and decreased the atmospheric transmissivity. However, this process happened without rainfall, since rain was just recorded in late September and early October (38.75 mm accumulation) (Figure 2H). In addition, August and September presented the cumulative effect of dust, smoke and aerosols - coming from other Amazon and Cerrado regions - that were dispersed and transported through the lower atmosphere (Palácios et al., 2018). The combined factors mitigate part of the global radiation and may be responsible for H_G and insolation oscillations in the region during the dry season.

D. alata seedlings recorded accumulated evapotranspiration (ETc) 486.6, 441.8, 418.0, 422.7 and 397.0 mm under full sun and black polyolefin screen (45.3%, 54.1%, 68.3% and 83.3% shading, respectively) conditions (Figure 3). The colored polyolefin screens recorded 366.4, 344.9, 342.0 and 390. mm accumulated evapotranspiration (ETc) under shading conditions with thermo-reflective, red, blue and green screens, respectively. The accumulated ETc recorded significant differences between the full sun and black screen (shading higher than 54%) conditions, whereas the qualitative (spectral) solar radiation evaluations did not show significant accumulated ETc differences between colored screens (Figure 3D).

D. alata seedlings grown under full sun presented higher evapotranspiration demand than the ones grown under shading screen conditions due to the interaction among the higher H_G incidence - which generated higher Tair and lower RH-, the winds and the higher warming of the substrate and of the water stored in the lysimeter system. These conditions generated higher water steam deficit at the substrate/plant-atmosphere interface; consequently, it increased ETc. Similarly, Monteiro et al. (2016) investigated the ETc of six tropical forest species from May to September 2014 in Sinop County – MT. They recorded mean accumulated ETc 403.25 mm for plants grown under full sun condition; 328.89, 281.4 and 242.71 mm for the ones grown under black polyolefin screens (35 %, 50 % and 80 % shading, respectively); and 305.22, 302.51, 296.00 mm for plants grown under green, red and blue polyolefin screens, respectively.

The evapotranspiration of a given species can be influenced by water availability, local meteorological conditions (solar radiation, air temperature, relative air humidity and wind speed), edaphic factors (soil physicochemical structure), crop factors (species, crop type, developmental stage) and by management techniques (fertilization, irrigation, pest and disease control). These variables can change the microclimate and vegetation dynamics (Yarami et al., 2011; Filho et al., 2015; Silva et al., 2015; Silva et al., 2016; Oliveira et al., 2017).

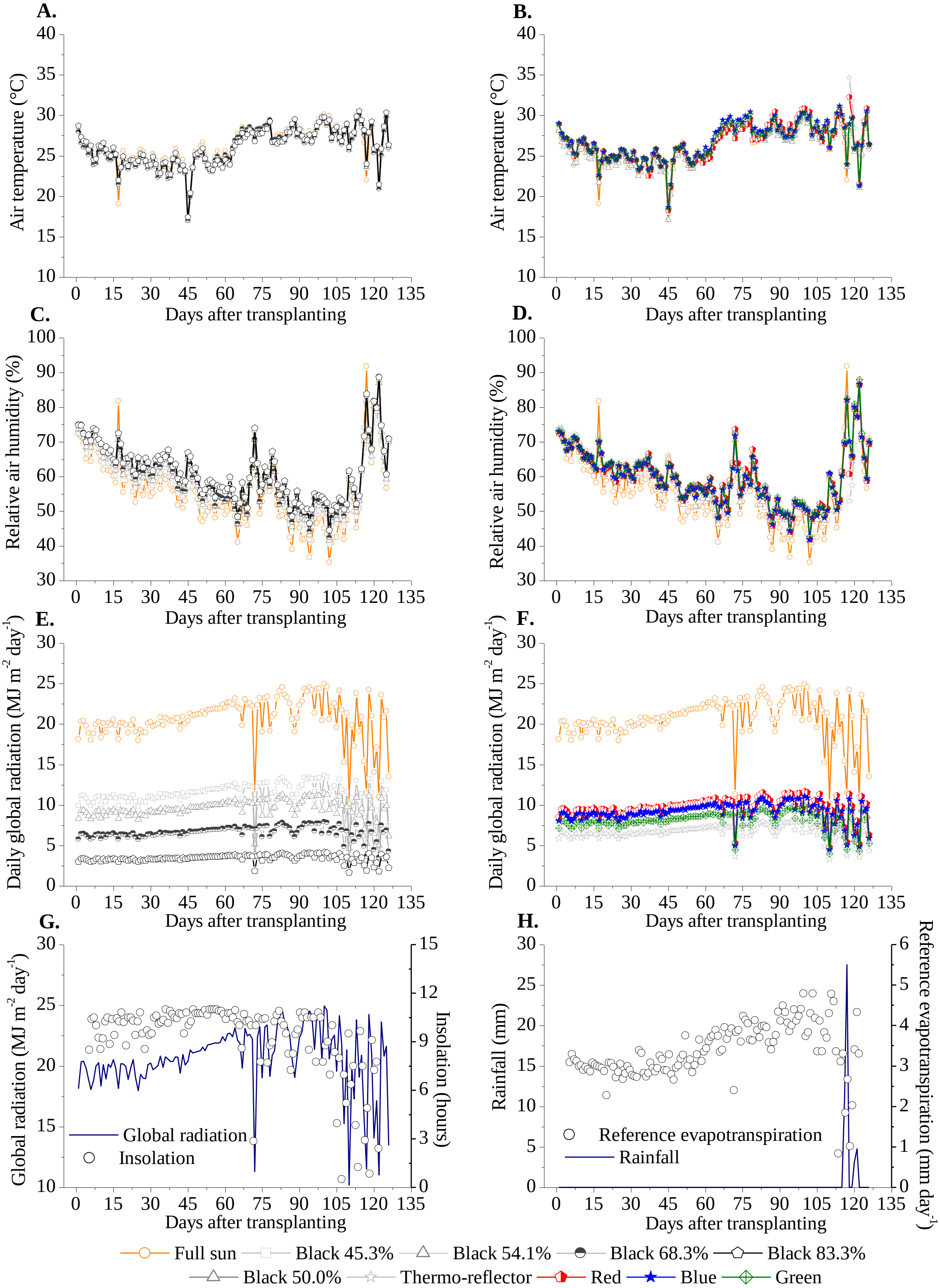

Figure 2. Mean daily air temperature (A, B), relative air humidity (C, D) and global radiation (E, F) in suspended nurseries covered with different shading screens, insolation (G), rainfall and reference evapotranspiration (H) in full sun from June 4 to October 7, 2017 (from 0 to 125 DAT) in Sinop County – MT.

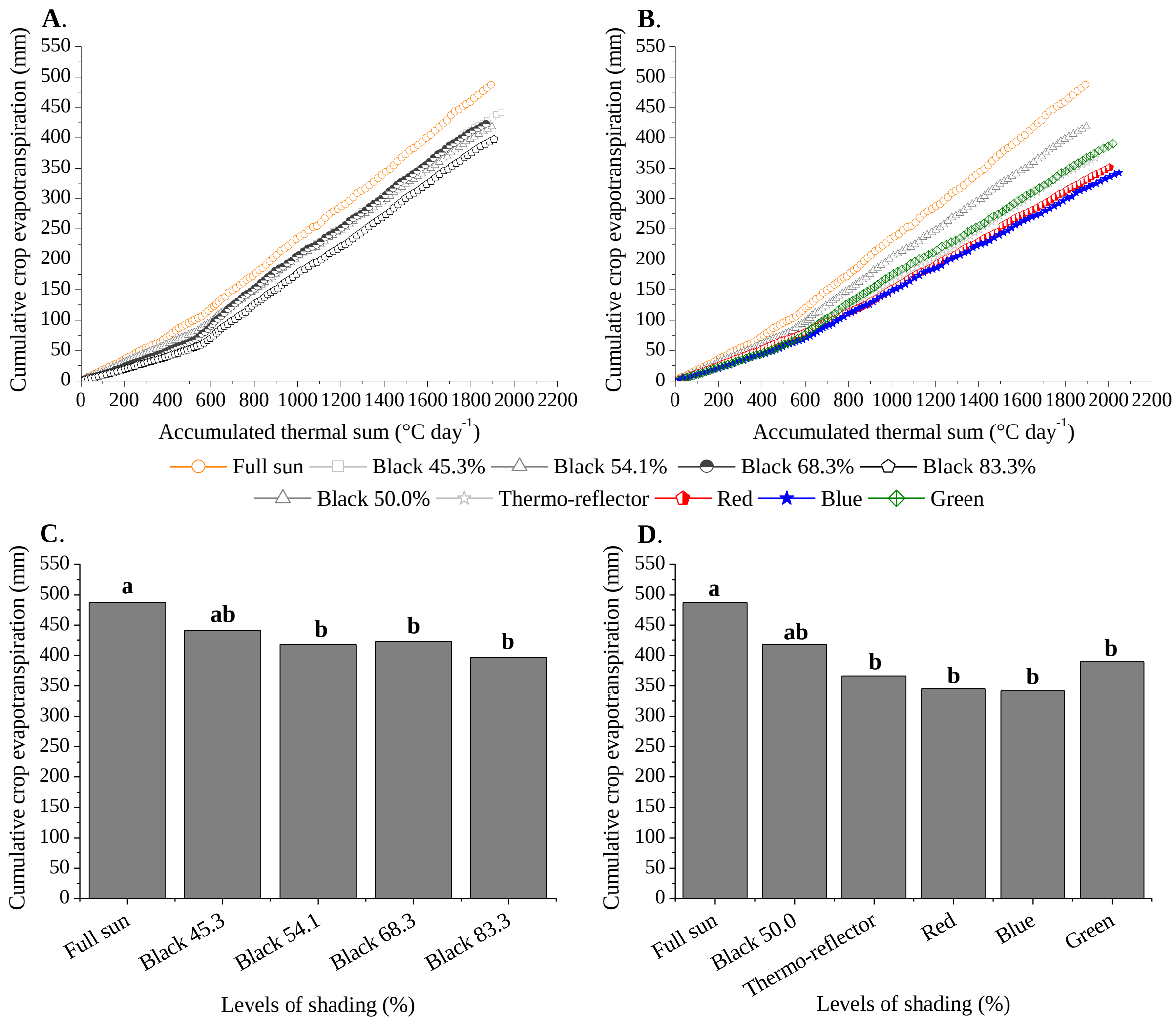

Figure 3. Accumulated evapotranspiration potential (mm) of *D. alata* seedlings at quantitative (A) and qualitative (B) shading levels, based on the accumulated thermal sum between June 4 and September 27, 2017 in Sinop County - MT. Means followed by the same letter did not differ from each other in Tukey test, at 5% probability level.

Plant-related factors define and modify evapotranspiration (ET) rates, besides directly affecting the soil-to-atmosphere water-movement resistance (Pereira et al., 2013). This dependence may be more evident in forest nurseries due to different leaf morphologies and anatomies, large variations in leaf, leaflet and foliole distribution, among other plant structures, as well as to internal water transport-resistance variations (water potential) and to other morphological aspects influencing evapotranspirometric surfaces.

Thus, ETc values recorded under forest nursery conditions change depending on species (Monteiro et al, 2016), environmental crop conditions and crop containers (Silva et al., 2015), substrates, cultivation time, as well as on nutritional and phytosanitary conditions in the crop.

The daily ETc and Kc oscillations in *D. alata* seedlings grown under different shading screens (Figure 4) resulted from internal micrometeorological dynamics under each crop condition, such as increased H_G incidence in August (higher than 600 ADD) and its influence on Tair and RH, besides the development of seedlings presenting expanded leaf area. The combination of these factors and plant physiological adaptation responses to the light-intensity conditions in the crop were responsible for the ETc increase.

The highest daily ETc and Kc values (4.34 mm day^{-1} and 1.23) were recorded under full sun condition; they decreased as the shading level increased (Figure 4). The low Kc values found in the early plant developmental stage, regardless of the shading condition, resulted from low evapotranspirometric surface (leaf area), since the substrate was subjected to field capacity conditions (Table 1).

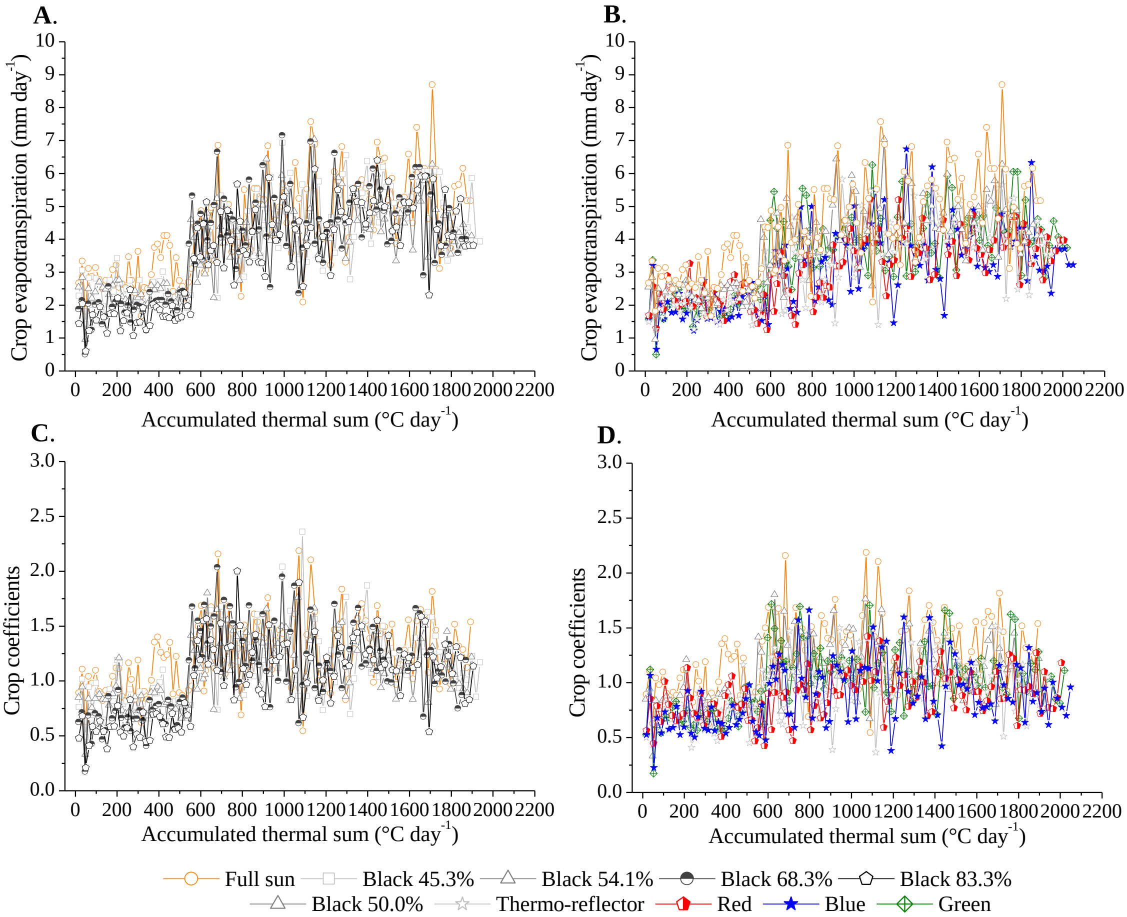

Figure 4. Mean daily evapotranspiration potential (A and B) and crop coefficient (C and D) values recorded for *D. alata* seedlings, according to quantitative and qualitative shading levels, based on the accumulated thermal sum recorded in Sinop County – MT, from June 4 to September 27, 2017.

Results recorded for the herein applied different shading conditions differed from the ones found by Silva (2012), who recorded ETc mean 7.32 and 3.39 mm day^{-1}, as well as mean Kc of 0.98 and 0.73, for *D. alata* seedlings grown in plastic bags and pots, under greenhouse condition, for 200 days. However, our results showed similarity to the ones found by Monteiro et al. (2016), who analyzed seedlings of six tropical forest species grown under different shading conditions during the dry season in Sinop County (MT) and recorded higher ETc and Kc values for plants grown under full sun condition, as well as decreased values as the shading level increased, regardless of the species.

The definitions of phenophases used to determine mean ETc and Kc values for forest seedlings are incongruous due to the incidence of vegetative phases with foliar differentiations. Therefore, the mean ETc and Kc values showed significant differences between months and shading screens – ETc and Kc values increased over time (Figure 5).

The ETc value under full sun condition increased by 2.73 mm (100%) between June and September – the mean increase was 0.91 mm month^{-1} (Figure 5). The black polyolefin screens (45.3%, 54.1%, 68.3% and 83.3% shading) recorded 90.8%, 85.9%, 86.9% and 81.6% accumulated ETc in baru seedlings in comparison to the full sun condition. On the other hand, the red, blue and green polyolefin screens, as well as the thermo-reflective screen, recorded 70.9%, 70.3%, 80.1% and 75.3% accumulated ETc in comparison to the full sun condition.

The cumulative effect of seedling growth, and its influence on ETc and Kc, were evaluated through the destructive analysis applied to the seedlings at 125 DAT. Seedling stem diameter and the leaf area of the cultivated seedlings recorded significant differences at quantitative (increasing) shading levels (Table 1). The highest mean seedling stem diameter values were recorded for plants grown under black screen (45.3% shading) and full sun conditions (5.34 and 5.33 mm day^{-1}), whereas the smaller diameter (4.69 mm day^{-1}) was recorded for plants subjected to the black screen (68.3% shading). The largest and smallest leaf areas were found in seedlings grown under black screen (83.3% shading) and full sun condition.

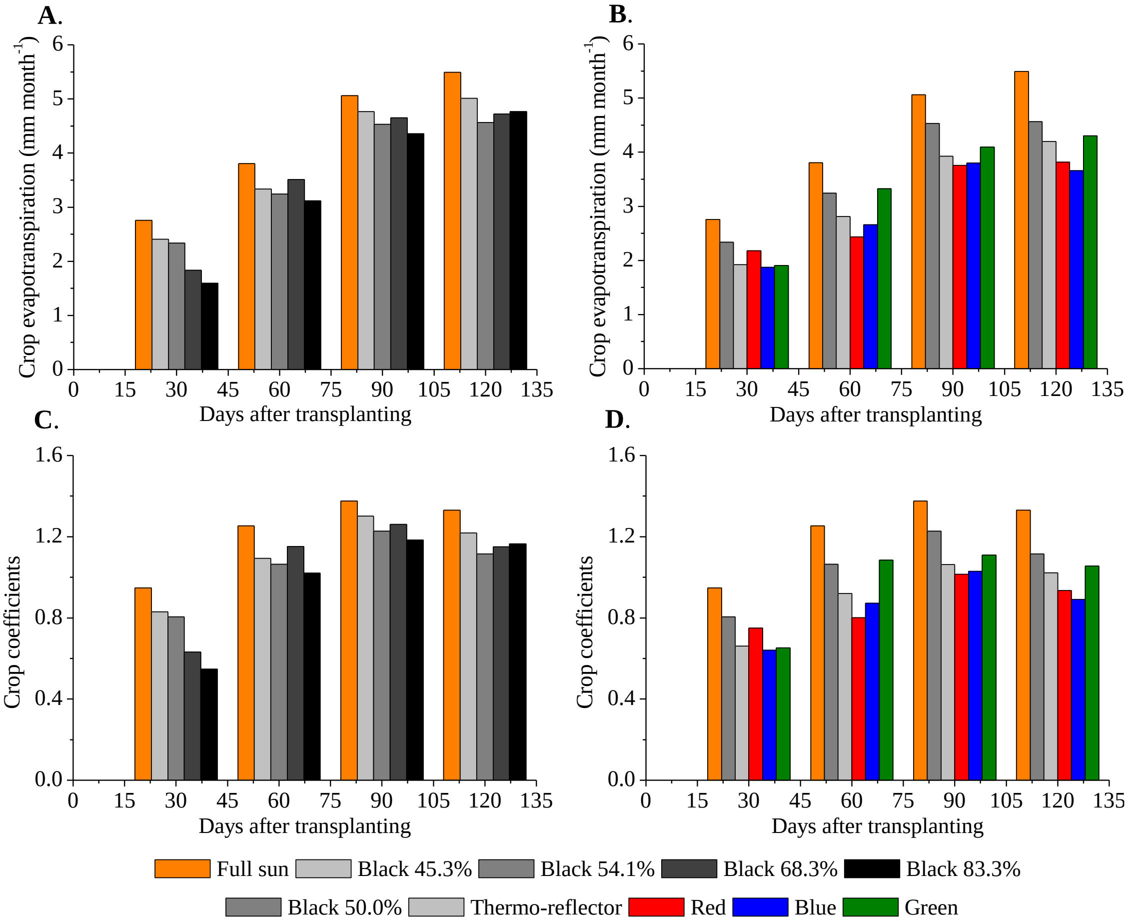

Figure 5. Mean monthly crop evapotranspiration potential (A, B) and crop coefficient (C, D) values recorded for *D. alata* seedlings subjected to different solar radiation levels between June 4 and September 27, 2017; Sinop County - MT.

D. alata seedlings subjected to different qualitative (spectral) shading levels presented significant differences in leaflet diameter, number of leaflets, leaf area and root length (Table 2).

Unlike results found in the current study, Ajalla et al. (2012), Mota et al. (2012) and Queiroz and Firmino (2014) found significant differences in other morphometric variables (plant height, number of leaves, number of leaflets, root length and total dry mass) analyzed in *D. alata* seedlings grown under different shading conditions.

However, *D. alata* seedlings investigated in the current study presented some adaptations under full sun condition, among them: leaf inclination parallel to the incidence of solar radiation, reduced number of leaves and, consequently, reduced leaf area and thicker leaf blade (leaflets) - these results corroborate the study by Brant et al. (2011). These adaptations show the species' ability to physiologically regulate itself according to crop environment.

The early developmental stage of plants subjected to higher shading conditions tends to present leaf expansion as strategy to enable plants to increase their photosynthetic surface in order to better use the low intensity of the incident solar radiation. Species adapted to low- and high-luminosity conditions present anatomical structure (stomata arrangement, density and size; epidermal thickness) and physiological properties (CO_2 absorption, chlorophyll content) that enable them to effectively use the available solar radiation (Marenco et al., 2017).

Overall, seedlings grown under blue screen condition recorded the lowest mean values for diameter, number of leaves and leaf area, whereas those subjected to the thermo-reflective screen presented the shortest mean root length (Table 2). Seedlings grown under the green screen presented the largest mean number of leaflets and leaf area, besides the longest mean root length.

Table 1. Mean values of morphometric growth parameters applied to *D. alata* seedlings (at 125 DAT) subjected to quantitative shading levels, in Sinop County - MT, 2017.

Parameters	Ful sun	Black 45.3%	Black 54.1%	Black 68.3%	Black 83.3%	Mean	MSD
Height (cm)	13.53 a	13.34 a	13.12 a	12.20 a	13.58 a	13.17	1.98
Diameter (mm)	5.33 a	5.34 a	5.12 ab	4.69 b	4.95 ab	5.1	0.6
Number of leaves	3.57 a	4.28 a	3.80 a	3.48 a	4.50 a	3.95	1.39
Number of leaflets	21.90 a	28.00 a	22.72 a	23.05 a	26.64 a	24.66	8.98
Leaf area (cm²)	93.02 b	156.95 ab	156.64 ab	136.47 ab	243.61 a	157.34	136.82
Root length (cm)	15.62 a	15.01 a	17.32 a	20.18 a	20.93 a	17.63	6.57
Root volume (cm³)	2.33 a	2.21 a	2.64 a	2.38 a	3.00 a	2.5	0.99
DM roots (g)	0.77 a	0.72 a	0.77 a	0.70 a	0.92 a	0.77	0.34
DM stem (g)	0.74 a	0.83 a	0.82 a	0.62 a	0.78 a	0.76	0.29
MD leaves (g)	1.47 a	1.62 a	1.62 a	1.56 a	1.91 a	1.64	0.59
DM total plant (g)	2.98 a	3.17 a	3.21 a	2.88 a	3.62 a	3.17	1.15

DM – dry matter (g); MSD - minimum significant difference. Means followed by the same letter did not differ from each other in the Tukey Test, at 5% probability level.

Light is essential to the expansion and development of the photosynthetic apparatus, since its quality and availability influence biomass production and partition, as well as dry matter production and leaf area size (Wang et al., 2015).

The blue wavelength stimulates stomatal opening, which enables increased gas exchange, internal CO_2 concentration, stomatal conductance, photosynthetic activity and osmoregulation of guard cells; consequently, the leaf area increases (Wang et al., 2015). Thus, the current study recorded negative blue wavelength blocking effect on the early development and evapotranspiration of *D. alata* seedlings.

According to other studies about the early development of species *D. alata*, seedlings exposed to different nutrient concentrations (Silva et al., 2016), water depths and container sizes (Silva et al., 2015), and even seedlings grown in degraded areas in the Cerrado biome (Saboya and Borghetti, 2012; Mizobata et al., 2017), presented strong resilience and survival to several environmental conditions.

In light of the foregoing, our study evidenced the adaptability of species *D. alata* to different environmental conditions during its early developmental stage, with emphasis to the extraordinary phenotypic and genotypic plasticity of this species when it was subjected to different quantitative and qualitative solar radiation levels.

Table 2. Mean values of morphometric growth parameters applied to D. alata seedlings (at 125 DAT) subjected to different qualitative shading levels in Sinop County - MT, 2017.

Parameters	Full sun	Black 50.0%	Thermo-reflector	Red	Blue	Green	Mean	MSS
Height (cm)	13.53 a	13.12 a	12.44 a	13.09 a	12.15 a	13.44 a	13	2.28
Diameter (mm)	5.33 a	5.12 a	5.09 ab	5.09 ab	4.52 b	5.14 a	5.07	0.59
Number of leaves	3.57 a	3.80 a	3.26 a	3.74 a	3.25 a	3.95	3.62	1.27
Number of leaflets	21.90 ab	22.72 ab	21.37 ab	23.78 ab	16.76 b	25.85 a	22.26	7.49
Leaf area (cm²)	93.1 bc	156.6 ab	149.8 abc	139.4 abc	77.04 c	187.7 a	133.92	73.07
Root length (cm)	15.62 b	17.32 ab	14.37 b	16.98 ab	17.74 ab	20.61 a	17.11	4.45
Root volume (cm³)	2.33 a	2.64 a	3.00 a	3.17 a	2.88 a	3.05 a	2.84	1.12
DM roots (g)	0.77 a	0.77 a	0.91 a	0.89 a	0.79 a	0.94 a	0.84	0.34
DM stem (g)	0.74 a	0.82 a	0.84 a	0.75 a	0.74 a	0.85 a	0.79	0.27
MD leaves (g)	1.47 a	1.62 a	1.95 a	1.72 a	1.65 a	2.08 a	1.75	0.68
DM total plant (g)	2.98 a	3.21 a	3.70 a	3.36 a	3.18 a	3.86 a	3.38	1.13

DM – dry matter (g); MSD - minimum significant difference. Means followed by the same letter did not differ from each other in the Tukey Test, at 5% probability level.

CONCLUSIONS

The increased shading level decreased the evapotranspiration potential and crop coefficients of *D. alata* seedlings.

Different quantitative levels and spectral (qualitative) shading quality did not affect the growth of *D. alata* seedlings; however, the leaf area increased as the shading level increased.

D. alata seedling production depends on the cost-benefit ratio of shading screens and local water availability - production in full sun condition is recommended whenever water is not a limiting factor.

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Conflict of interest statement. The authors declare that there are no competing interests. Institute of Physics of the Federal University of Mato Grosso, Brazil, approved the present study for its development.

Compliance with ethical standards. This article does not contain studies carried out with human beings, therefore, there was no need for approval by the Research Bioethics Committee of the Sinop University Campus of the Federal University of Mato Grosso, Brazil, for its development.

Data availability. The databases are available with the corresponding author (adilsonpacheco@ufmt.br or pachecoufmt@gmail.com) upon reasonable request.

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