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Water requirements and crop coefficients of tropical forest seedlings in different shading conditions

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Key words:
evapotranspiration
irrigation management
leaf area
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A B S T R A C T

The objective was to determine the crop evapotranspiration (ETc) and crop coefficients (Kc) of tropical forest seedlings over a 135-day cycle, in the climatic conditions of the Cerrado-Amazon transitional region (11° 51' 08 "S; 55° 30' 56" W; altitude of 371 m). Five native species (*Tabebuia impetiginosa*, *Tabebuia roseoalba*, *Handroanthus chrysotrichus*, *Parkia pendula* and *Parkia platycephala*) and one exotic species (*Adenanthera pavonina*) were evaluated in seven shading conditions: 35, 50 and 80% black nets (Polyolefin); green Frontinet®, red ChromatiNet® and blue ChromatiNet® of 50% shading; and full sun. Reference evapotranspiration (ETo) was obtained by the Penman-Monteith FAO-56 method and the crop evapotranspiration of the seedlings (ETc) was given by daily weighing. The Kc values were obtained by dividing ETo by ETc. At 135 DAT, destructive analysis was performed to determine the leaf area. In full sun conditions, ETc varied from 3.9 (*P. pendula*) to 5.0 mm d^{-1} (*T. roseoalba*). The increase in the shading percentage promotes reduction in leaf area, ETc and Kc. Colored nets with 50% shading generate similar water demands.

Palavras-chave:
evapotranspiração
manejo de irrigação
área foliar
radiação solar

Necessidades hídricas e coeficientes de cultivo de mudas florestais tropicais em diferentes condições de sombreamento

R E S U M O

Objetivou-se, com este trabalho, determinar a evapotranspiração da cultura (ETc) e os coeficientes de cultivo (Kc) de mudas florestais tropicais, ao longo de 135 dias de ciclo, nas condições climáticas da transição Cerrado-Amazônia. Foram avaliadas cinco espécies nativas (*Tabebuia impetiginosa*, *Tabebuia roseoalba*, *Handroanthus chrysotrichus*, *Parkia pendula* e *Parkia platycephala*) e uma exótica (*Adenanthera pavonina*) em sete condições de sombreamento: telas poliolefinas pretas de 35, 50 e 80%; frontinet verde, chromatinet vermelha e chromatinet azul a 50% sombreamento e pleno sol. A evapotranspiração de referência (ETo) foi obtida pelo método de Penman-Monteith FAO-56 e a evapotranspiração real das mudas (ETc) foi dada por pesagem diária. Os valores de Kc foram obtidos pela razão entre ETo e ETc; aos 135 dias após o transplantio realizou-se a análise destrutiva para determinação da área foliar. Nas condições de pleno sol a ETc variou de 3,9 (*P. pendula*) a 5,0 mm d^{-1} (*T. roseoalba*). O aumento do percentual de sombreamento proporciona diminuição da área foliar, da ETc e do Kc; enfim, as telas coloridas com 50% de sombreamento geram demandas hídricas semelhantes.

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Introduction

Meeting the water demand of a vegetation promotes conditions for the expression of the maximum productive potential of the plant and ensures the sustainability and preservation of environmental systems, for subsidizing the planning, project and management of hydro-agricultural systems (Gomide & Albuquerque, 2008; Carvalho et al., 2015).

According to Souza et al. (2014), only the knowledge on the total water requirement of the plant does not lead to an efficient irrigation management; hence, the knowledge on the water demand in different development stages becomes essential. When applied in hydro-agricultural systems, crop evapotranspiration (ETc) must incorporate physiological and morphological characteristics of the plant and their interactions with crop management and soil physicochemical factors, with variations along the cycle due to the growth rates and, as a result, to the variation in soil cover (Doorenbos & Pruitt, 1997; Allen et al., 1998; Lena et al., 2011).

In forest nurseries, irrigation assumes an important role, for allowing the production in different periods of the year and application of water in adequate amount and moment, achieving gains in the quality of seedlings (Lopes et al., 2005; Thebaldi et al., 2014). The adoption of irrigation systems with design errors and/or with water managements inadequate for the production of forest seedlings may lead to yields lower than the genetic potential of the species, favor the establishment of diseases, increase the consumption of nutrients, water and energy, besides decreasing germination potential and homogeneity in the development of the seedlings (Lopes et al., 2005; Gruber, 2006; Neves et al., 2010).

Considering the great floristic diversity of tropical and native forest species with multiple potential uses (wood, food, medicinal, pulp and paper, ornamental, recovery of degraded areas, etc.), it becomes necessary to implement improvements in the process of production of seedlings, ensuring quantity and quality and, consequently, the achievement of higher potentials of survival and good establishment at the field. Therefore, this study aimed to determine ETc and the crop coefficients of six tropical forest species in the stage of seedlings under different shading conditions, in the climatic conditions of the Cerrado-Amazon transitional region of the state of Mato Grosso, Brazil.

Material and Methods

The study was carried out from May to September 2014, at the Plant Production Sector of the Federal University of Mato Grosso, Campus of Sinop-MT, Brazil (11º 51' 0.8" S; 55º 30' 56" W; 371 m). According to Köppen's climate classification, the predominant climate in the Mid North region is Aw (hot and humid tropical), characterized by the presence of two well defined seasons: rainy (October to April) and dry (May to September), with low annual thermal amplitude (monthly means from 24 to 27 ºC) and mean annual rainfall around 1974 mm (Souza et al., 2013).

The experimental design was completely randomized, in a 7 x 6 factorial scheme, composed of 7 shading conditions and 6 forest species, with 12 replicates. The following nets were used: 50% blue ChromatiNet®, 50% red ChromatiNet®, 50% green Frontinet®, 35, 50 and 80% Sombrite® (black), and the condition of full sun. The studied forest species were: *Parkia platycephala* (Benth.), *Parkia pendula* (Willd.) Benth. ex Walp., *Tabebuia roseoalba* (Ridl.) Sandwith, *Handroanthus chrysotrichus* (Mart. ex. A. DC.) Mattos, *Tabebuia impetiginosa* (Mart. ex DC. Standl.) and *Adenanthera pavonina* L., which are popularly known as 'visgueiro', 'angelim saia', 'ipê branco', 'ipê amarelo', 'ipê rosa' and 'falso-pau-brasil', respectively.

Under the full sun condition, the meteorological monitoring was performed close to the experimental unit through an automatic weather station (AWS) equipped with a CR 1000 (Campbell Scientific) data acquisition system and composed of the following sensors: global solar radiation (CS300 pyranometer - Campbell Scientific Company), photosynthetically active radiation (PAR Lite - Kipp & Zonen Company) and psychrometer with thermometer shelter (108 Probe Temperature - Campbell Scientific Company) at height of 2.0 m, wind speed and direction (03002-L RM anemometer - Young Company) at height of 10.0 m and rain gauge (TE 525 - Campbell Scientific Company) at height of 1.50 m. The meteorological data were collected as mean values every 5 min, subsequently obtaining the total, mean, maximal and minimum daily values of the variables used for the determination of reference crop evapotranspiration (ETo, Eq. 1) through the Penman-Monteith FAO-56 method - PMF 56 (Allen et al., 1998). In the other evaluated treatments, digital thermo-hygrometers (KlimaLogg Pro, TFA Dostmann GmbH & Co.KG) were installed for routine monitoring of air temperature (Tair) and relative air humidity (RH) with intervals of 10 min.

$$ETo = \frac{0.408\Delta\left(Rn - G\right) + \gamma \frac{900}{T + 273} u_2 \left(es - ea\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \quad (1)$$

where:

ETo - reference evapotranspiration, mm d^{-1};

Rn - radiation balance, MJ m^2 d^{-1};

G - heat flow in the soil, MJ m^2 d^{-1} (G = 0.03 Rn was adopted);

T - daily mean air temperature at height of 2 m, ºC;

u_2 - wind speed at height of 2 m, m s^{-1};

es - saturation vapor pressure, kPa;

ea - actual vapor pressure, kPa;

Δ - slope of the curve vapor pressure versus temperature, kPa $ºC^{-1}$; and,

γ - psychrometric constant, kPa $ºC^{-1}$; 0.408 corresponds to 1/λ, where λ is the latent heat of water vaporization, equal to 2.45 MJ kg^{-1}; 900 for the conversion of units.

These variables were estimated according to the recommendations of Pereira et al. (1997) and Allen et al. (1998).

Germination occurred in a controlled environment (air temperature of 30 ºC and photoperiod of 12 h) and the seedlings were transplanted to trays of 128 cells until the appearance of the first pair of true leaves. The seedlings were transplanted (April 24, 2014) to cylindrical black polyethylene bags (28.50 x 14.50

cm - height x diameter) with lateral perforations in order to drain the excess water. The substrate consisted of the mixture of forest soil (dystrophic Red Yellow Latosol) and the commercial substrate Plantmax at the proportion of 3:1, fertilized with 500 g of granular NPK (4-14-8) fertilizer per m^3 of soil.

The seedlings were placed in East-West oriented, suspended nurseries (1.0 m from the soil), with dimensions of 3.0 x 1.0 x 1.0 m (length, width and height), opened at the bottom (½" wire mesh) and covered on the sides and on the top by the shading nets (except for "full sun").

For the determination of daily evapotranspiration of the seedlings, daily weighing was performed on a digital scale with 0.001 g of precision. As a reference, the mass of the containers with the seedlings after saturation and free water drainage (saturated/drained substrate) was considered, obtained in maximum intervals of 30 days. The masses of water lost by the substrate/plant (evapotranspiration) were determined through direct weighing, on a daily basis (ETc). Water replenishment was equivalent to the total loss of water, given by the difference between the mass of the saturated/drained substrate (reference) and the mass of evapotranspired water. Subsequently, the crop coefficients for each evaluated species were established based on the ratio between ETc and PMF-56 ETo. ETc measurements occurred between May 6, 2014 (12 days after transplanting - DAT) and September 6, 2015 (135 DAT).

For the production of seedlings of native forest species (except for *A. pavonina*), there is no technical criterion to determine the optimal age of the seedlings for planting, which has significantly affected the quality, especially of the root system. According to Mafia et al. (2005), the malformation of the root system prevents the absorption of water and nutrients in amounts sufficient to meet the requirements of the plant, resulting in a symptomatology typical of water and/or nutritional deficiency, as a consequence of the imbalance between roots and shoots. Thus, for the establishment of the end of the cycle of the "seedling" stage, the maximum time of absence of tangled, crooked and strangled roots was adopted as a criterion.

Therefore, for all species evaluated at 135 DAT, the seedlings were subjected to destructive analysis for the determination of leaf area (LA, cm^2), using a benchtop photoelectric meter (L3000 - Li-Cor Company), and the dry matter in a forced-air oven at 65 ºC (Benincasa, 2003). The differences between the means, when significant, were compared by analysis of variance by F test and Tukey test, at 0.05 probability level.

Results and Discussion

During the experiment, there were only 27.00 mm of rainfall distributed until 42 DAT, indicating the occurrence of favorable climatic conditions for the analysis of the specific influence from shading conditions on each species and condition (Figure 1). In general, the highest daily thermal amplitudes occurred in July and August, with mean daily differences in maximum and minimum temperatures of 16.64 and 17.76 °C, respectively.

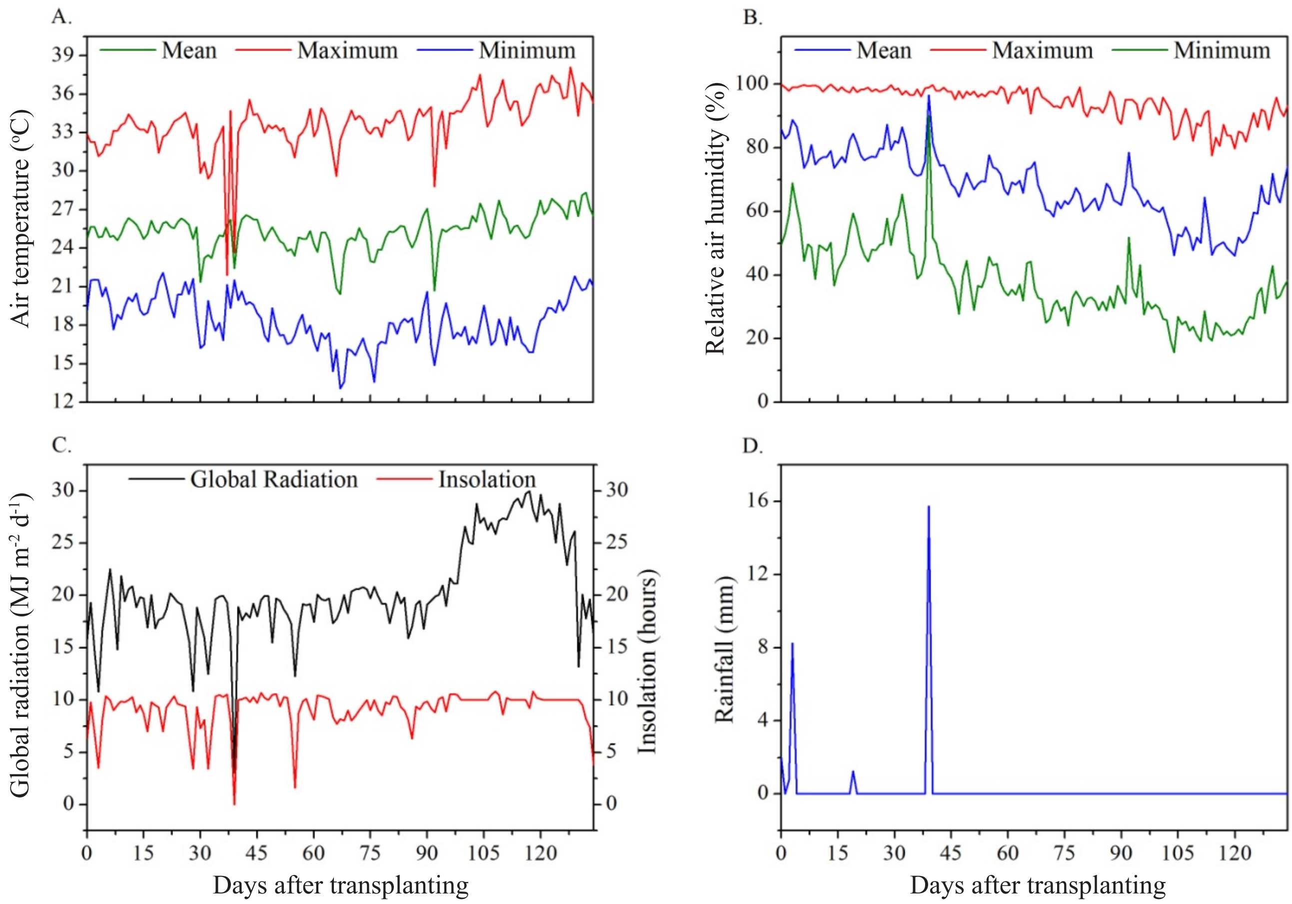

Figure 1. Daily variations of air temperature (A), relative air humidity (B), global radiation, insolation (C) and rainfall (D) from April 4 to September 6, 2014 (0 to 135 days after transplanting)

The monthly means of air temperature (Tar) varied from 24.61 °C (June) to 27.03 °C (September), corroborating with the behavior described by Souza et al. (2013). The monthly means of relative air humidity (RU) from April to September were 83.4, 78.2, 72.0, 64.1, 54.1 and 69.8%, respectively, with minimum daily value of 24.8% in August. In addition, there was an increase in the incident global radiation from 90 DAT on (July), due to the increment in the atmospheric transmissivity; in August, the daily means of global radiation and insolation were 27.1 MJ m^{-2} d^{-1} and 10.0 h.

According to Carvalho et al. (2015), if there is no water restriction, the PMF-estimated ETo is proportional to the availability of solar energy and to the radiation balance. Hence, it is pointed out that, for the studied region, there is an inversion of the seasonal behavior of global radiation and insolation along the year, with higher values in the winter and lower values in the summer and, consequently, of Tair (maximum values in the winter, higher than 35 °C). Since water vapor has great potential to attenuate the radiation in the atmosphere during months of summer or rainy period, the differences between night and day temperatures are lower, with great decrease of maximum temperature, due to the alterations in the totals of the direct and diffuse components with nebulosity (Santos et al., 2013).

Throughout the cycle of production of the seedlings, the lowest cumulative ETc values were obtained by *P. platycephala* (full sun) and *P. pendula* (other shading conditions) (Table 1). Therefore, regardless of the shading level, the highest water demands (ETc) occurred for *T. impetiginosa*, for which the condition of full sun (483.49 mm) generated increments of 23.1, 35.5 and 46.4% in ETc, when compared with the black nets of 35, 50 and 80% shading, respectively; also, when compared with the colored nets, there were increments in ETc from 23.4 (green) to 29.7% (blue).

Through the destructive analysis of the seedlings at 135 DAT, it was observed that *P. pendula* and *P. platycephala* showed the lowest means of leaf area, in all shading conditions, while *T. impetiginosa* accumulated a minimum of 550.94 cm^2 of leaf area (Table 2). According to Villa-Nova et al. (1996), the leaf area index constitutes the biological factor with highest importance in the process of measurement of evapotranspiration, since it refers to the size of the transpiring surface. Hence, there is a tendency of increase in transpiration (consequently in evapotranspiration) with the increment in leaf area, a behavior that has been reported for annual and perennial crops (Muçouçah et al., 2006; Oliveira et al., 2009; Souza et al., 2014).

In general, the increase in the shading level reduced leaf area and ETc at 135 DAT, regardless of the species (Table 2). However, in the conditions of full sun, ETc oscillated from 3.94 to 5.00 mm d^{-1} for *P. pendula* and *T. roseoalba*, indicating that, at the end of the cycle of the "seedling" stage, some species showed higher leaf expansion rates in comparison to *T. impetiginosa*; in spite of that, the restriction of root development was adopted as the technical criterion of the optimal age.

Specifically for the studied species, the influence of species and development stage on ETc results from variations in leaf area, leaf morphological characteristics and canopy geometry, which affect the capacity of interception of solar radiation and

Table 1. Cumulative evapotranspiration (ETc) of seedlings of six tropical forest species under different cultivation conditions at 135 days after transplanting

Species	Full sun	Black 35%	Black 50%	Black 80%	Green	Red	Blue	Mean
				Cumulative crop evapotranspiration (mm)				
T. impetiginosa	483.49	371.76	311.98	259.22	370.57	365.35	340.01	357.48
T. roseoalba	410.21	334.28	265.04	237.39	296.33	274.53	299.06	302.41
H. chrysotrichus	462.62	365.47	322.22	258.86	345.64	361.23	328.71	349.25
P. pendula	327.60	271.56	238.70	216.67	247.10	262.47	253.46	259.65
P. platycephala	314.80	272.85	254.67	237.15	270.22	272.43	262.96	269.30
A. pavonina	420.80	357.40	296.00	246.99	301.45	279.07	291.79	313.36
Means	403.25	328.89	281.44	242.71	305.22	302.51	296.00	-

Table 2. Leaf area and mean daily evapotranspiration of seedlings of six tropical forest species under different cultivation conditions at 135 days after transplanting

Species	Full sun	Black 35%	Black 50%	Black 80%	Green	Red	Blue	Mean
				Leaf area (cm^2)				
T. impetiginosa	589.91Acd	729.46 Fc	774.19 Fd	550.94 Fa	931.90 Fg	777.06 Fe	780.92 Ff	733.48 F
T. roseoalba	301.52 BCa	155.50 Ce	125.69 Cd	65.77 Ca	156.94 Cf	94.99 Cb	122.12 Cc	146.07 C
H. chrysotrichus	172.76 CDab	239.69 Dg	193.08 De	76.45 Da	168.23 Dd	213.23 Df	113.88 Db	168.19 D
P. pendula	14.36 Ac	12.80 Aa	14.22 Ab	28.45 Be	23.44 Bd	55.03 Af	55.97 Ag	29.18 A
P. platycephala	43.46 Be	27.57 Bd	14.41 Ba	18.90 Ab	22.12 Ac	75.59 Bf	79.67 Bg	40.25 B
A. pavonina	408.18 Ef	345.49 Ee	300.02 Ec	165.05 Ea	341.45 Ed	246.54 Eb	441.50 E	321.18 E
Means	255.03 e	251.75 d	236.93 b	150.93 a	274.01g	243.74 c	265.68 f	239.72
				Crop evapotranspiration (mm d^{-1})				
T. impetiginosa	4.79	4.29	2.02	3.03	3.53	4.54	4.04	3.75
T. roseoalba	5.00	4.14	3.53	2.78	4.64	4.74	4.19	4.15
H. chrysotrichus	4.79	3.63	4.04	3.73	3.03	3.53	3.53	3.76
P. pendula	3.94	4.09	3.53	3.03	4.59	3.03	3.58	3.68
P. platycephala	4.19	4.04	3.23	3.48	3.63	3.03	3.89	3.64
A. pavonina	4.95	3.53	4.29	3.23	2.78	3.13	3.53	3.63
Means	4.61	3.95	3.44	3.21	3.70	3.67	3.79	3.77

Means followed by the same letter (uppercase in columns and lowercase in rows) do not differ by Tukey test 0.05 probability level the interaction with the wind and water vapor saturation deficit (Moura et al., 2013; Souza et al., 2014). Due to the increment in the transpiring surface of each species combined with the increase in incident solar radiation (Figure 1), there was an increasing behavior in daily ETc regardless of the shading condition (Figure 2). Similar responses of increase in water demand with the growth stage were observed by Sabonaro & Galbiatti (2007) in seedlings of *T. impetiginosa*.

The crop coefficients (Kc) and mean ETc values of the cycle (Table 3) indicate that only *T. impetiginosa* showed water demand higher than that of the reference crop (grass) when subjected to the conditions of full sun. According to Souza et al. (2014), the use of Kc in irrigation allows to determine the water demand for different crops; however, it has had little extension in its applications, because this coefficient varies among crops and along the production cycle.

Then, for the seedlings of forest species, there were small oscillations in Kc from 105 DAT on (Figure 3), regardless of the shading condition; this behavior results from the greater initial contribution of the evaporation of the water of the substrate, in

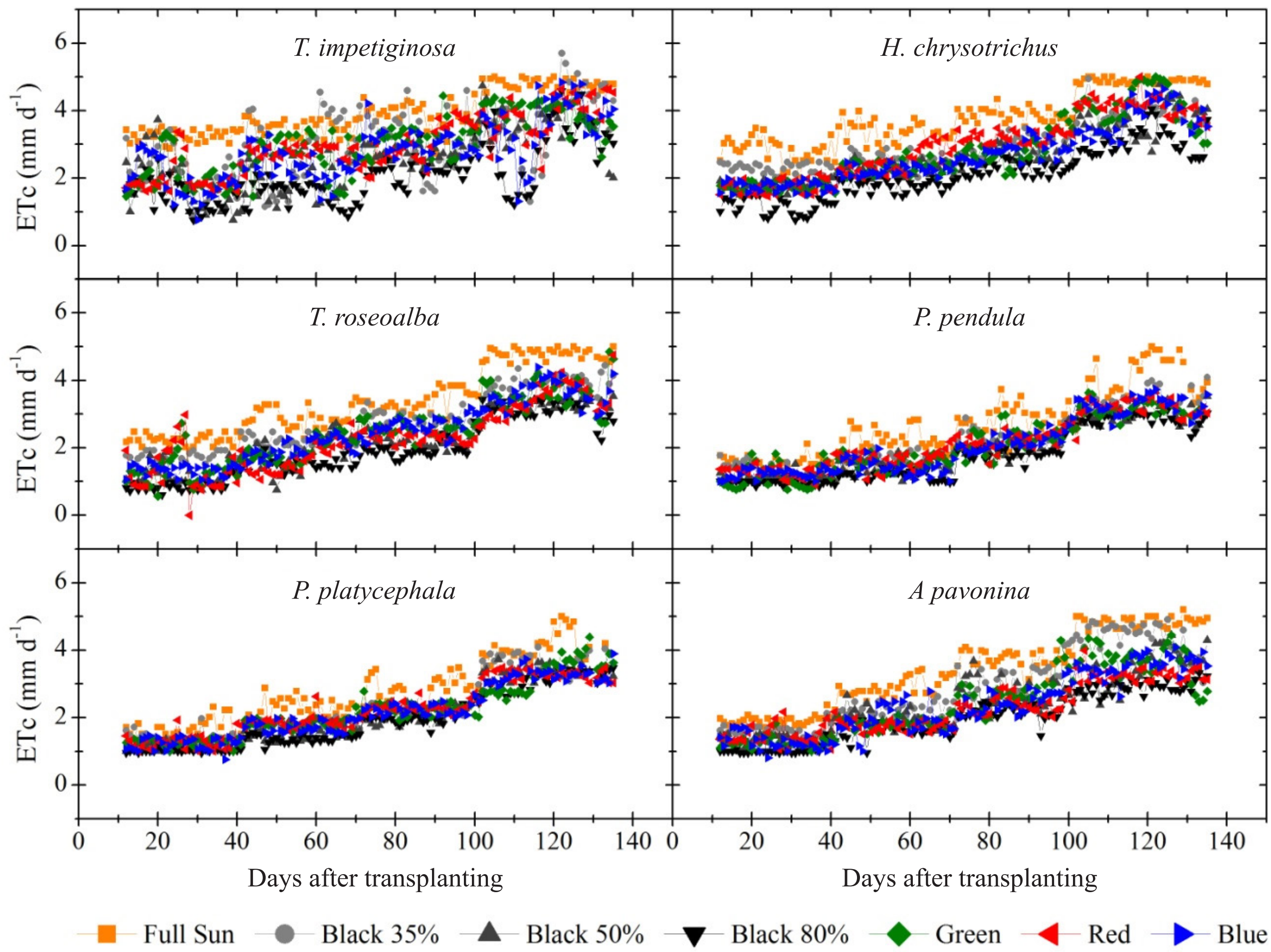

Figure 2. Daily crop evapotranspiration (ETc) for six tropical forest species in the stage of seedling, under different shading conditions, between 12 and 135 days after transplanting

Table 3. Mean daily evapotranspiration and crop coefficients for seedlings of six tropical forest species, under different shading conditions

Species	Full sun	Black 35%	Black 50%	Black 80%	Green	Red	Blue	Mean
Crop evapotranspiration – ETc (mm d^{-1})								
T. impetiginosa	3.90	3.00	2.58	2.09	2.99	2.95	2.76	2.90
T. roseoalba	3.36	2.72	2.15	1.93	2.41	2.23	2.43	2.46
H. chrysotrichus	3.76	2.97	2.62	2.10	2.81	2.94	2.67	2.84
P. pendula	2.69	2.21	1.94	1.76	2.06	2.13	2.06	2.12
P. platycephala	2.67	2.25	2.07	1.93	2.20	2.21	2.14	2.21
A. pavonina	3.39	2.88	2.39	1.99	2.43	2.25	2.35	2.53
Means	3.29	2.67	2.29	1.97	2.48	2.45	2.40	2.51
Crop coefficient (Kc)								
T. impetiginosa	1.03	0.78	0.66	0.54	0.78	0.77	0.72	0.75
T. roseoalba	0.87	0.71	0.55	0.49	0.62	0.57	0.63	0.63
H. chrysotrichus	0.99	0.78	0.68	0.54	0.72	0.76	0.69	0.74
P. pendula	0.69	0.57	0.49	0.44	0.52	0.55	0.53	0.54
P. platycephala	0.69	0.58	0.53	0.49	0.57	0.57	0.55	0.57
A. pavonina	0.88	0.74	0.62	0.52	0.62	0.58	0.61	0.65
Means	0.86	0.69	0.59	0.50	0.64	0.64	0.62	0.65

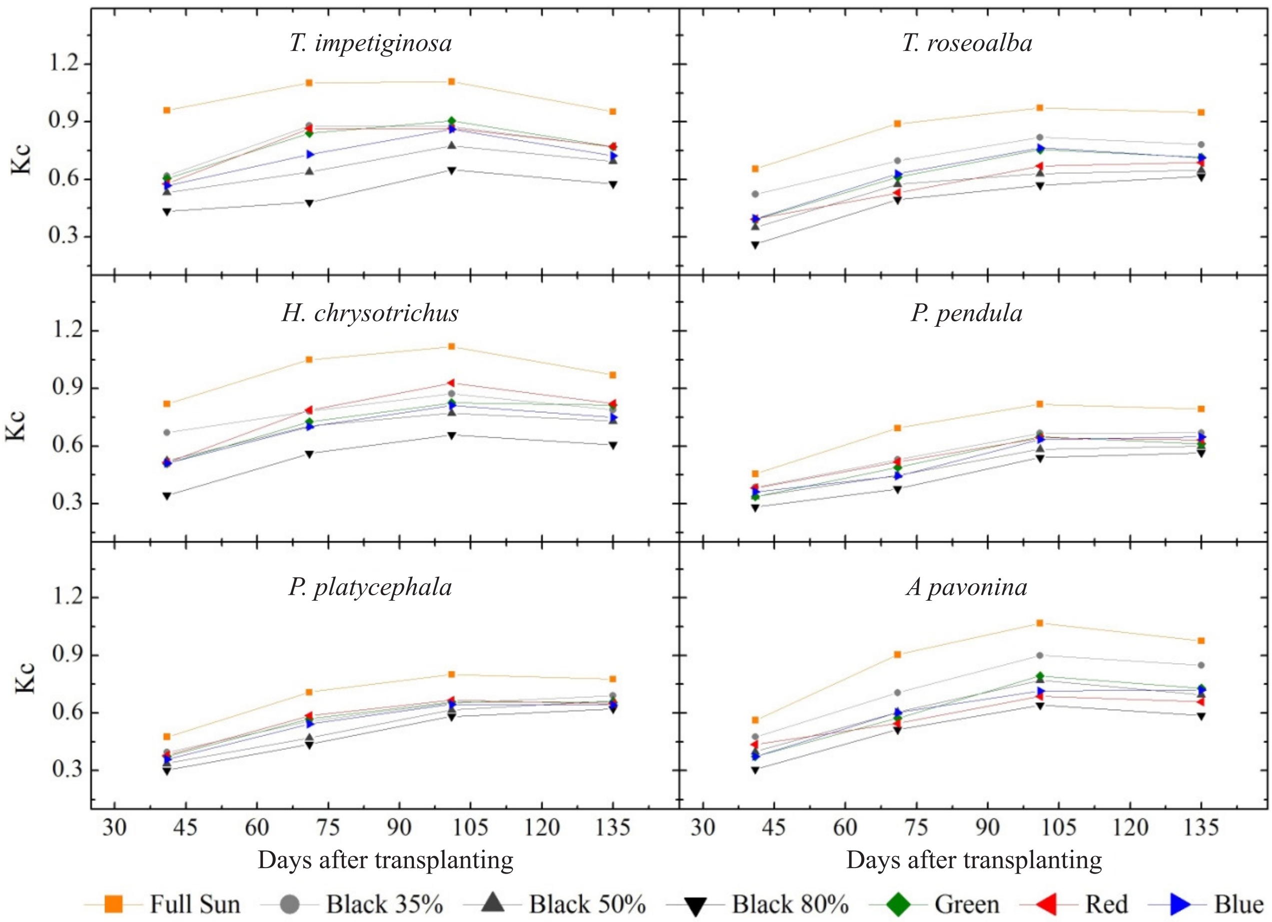

Figure 3. Mean crop coefficients (Kc) for six tropical forest species in the stage of seedling, under different shading conditions, between 12 and 135 days after transplanting

comparison to the transpiration of the plant, since a complete cover of the container does not occur in the initial stage. The observed values of ETc and Kc are within the values reported in the literature for perennial plants, in the initial stages of formation and implantation (Allen et al., 1998; Barboza Júnior, 2007; Silva, 2012).

For Carvalho et al. (2012), when using crop coefficients (Kc) for the estimation of evapotranspiration of a certain crop (ETc), it is important to identify the origin of Kc provided that the ETo estimation follows the same method and criteria originally adopted in the determination of Kc, indicating the necessity of determination and/or calibration for local cultivation conditions.

In general, there was a reduction in mean daily ETc and Kc with the increase in the attenuation of solar radiation (black nets) and, among the colored shading nets, the highest values of ETc and Kc were obtained using green Frontinet®, red ChromatiNet® and blue ChromatiNet®. Since ETc suffers great influence from local meteorological elements, specially Tair, RU, rainfall, wind and solar radiation, the evapotranspiration rate increases as temperature, wind speed and the availability of solar radiation increase and as relative air humidity decreases (Cunha & Escobedo, 2003; Lemos Filho et al., 2010). Therefore, the use of shading nets attenuates global radiation (and other meteorological elements), decreasing ETc (Fietz & Fisch, 2009). In turn, Kc results from the ratio between ETc and ETo and, therefore, the higher the shading level, the lower ETc and Kc tend to be.

Conclusions

1. The evapotranspiration (ETc) and the crop coefficients (Kc) of forest seedlings decrease with the increase in shading. The use of colored nets with 50% shading level increases the water demand of forest species, in comparison to black nets with the same shading level.

2. The forest seedlings with greater leaf area promote higher evapotranspiration rates and crop coefficients.

3. The crop coefficients of the six evaluated species varied from 0.49 to 0.78 under the shading conditions and from 0.69 to 1.03 under full sun.

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Literature Cited

Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M. Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. 1998. 300p. Irrigation and Drainage Paper, 56

Barboza Júnior, C. R. A. Evapotranspiração da lima ácida 'Tahiti' (*Citruslatifolia* Tan.) determinado por lisimetria de pesagem. Piracicaba: ESALQ, 2007. 63p. Dissertação Mestrado

Benincasa, M. M. P. Análise de crescimento de plantas: Noções básicas. 2. ed. Jaboticabal: FUNEP, 2003. 41p.

Carvalho, D. F.; Lima, M. E.; Oliveira, A. D.; Rocha, H. S.; Guerra, J. G. M. Crop coeficiente and water consumption of eggplant in no-tillage system and conventional soil preparation. Engenharia Agrícola, v.32, p.784-793, 2012. http://dx.doi.org/10.1590/S0100-69162012000400018

Carvalho, D. F.; Rocha, H. S.; Bonomo, R.; Souza, A. P. Estimativa da evapotranspiração de referência a partir de dados meteorológicos limitados. Pesquisa Agropecuária Brasileira, v.50, p.1-11, 2015. http://dx.doi.org/10.1590/S0100-204X2015000100001

Cunha, A. R.; Escobedo, J. F. Alterações micrometeorológicas causadas pela estufa plástica e seus efeitos no crescimento e produção da cultura de pimentão. Revista Brasileira de Agrometeorologia, v.11, p.15-26, 2003.

Doorenbos, J.; Pruitt, W. O. Necessidades hídricas das culturas. Campina Grande: UFPB, 1997. 204p.

Fietz, C. R.; Fisch, G. F. Avaliação de modelos de estimativa do saldo de radiação e do método de Priestley-Taylor para a região de Dourados, MS. Revista Brasileira de Engenharia Agrícola e Ambiental, v.13, p.449-453, 2009. http://dx.doi.org/10.1590/S1415-43662009000400012

Gomide, R. L.; Albuquerque, P. E. P. Agrometeorologia e otimização do uso da água na irrigação. Informe Agropecuário, v.29, p.72-85, 2008.

Gruber, Y. B. G. Otimização da lâmina de irrigação na produção de mudas clonais de eucalipto (*Eucaliptus urophylla* x *Eucaliptus grandis* e *Eucaliptus urophylla* var. *plathyphylla*). Piracicaba: ESALQ, 2006. 144p. Dissertação Mestrado

Lemos Filho, L. C. A.; Carvalho, L. G.; Evangelista, A. W. P.; Alves Júnior, J. Análise espacial da influência dos elementos meteorológicos sobre a evapotranspiração de referência em Minas Gerais. Revista Brasileira de Engenharia Agrícola e Ambiental, v.14, p.1294-1303, 2010. http://dx.doi.org/10.1590/S1415-43662010001200007

Lena, B. P.; Flumignan, D. L.; Faria, R. T. Evapotranspiração e coeficiente de cultivo de cafeeiros adultos. Pesquisa Agropecuária Brasileira, v.46, p.905-911, 2011. http://dx.doi.org/10.1590/S0100-204X2011000800017

Lopes, J. L. W.; Guerrini, I. A.; Saad, J. C. C.; Silva, M. R. Efeitos da irrigação na sobrevivência, transpiração e no teor relativo de água na folha em mudas de *Eucalyptus grandis* em diferentes substratos. Scientia Florestalis, v.68, p.97-106, 2005.

Mafia, R. G.; Alfenas, A. C.; Siqueira, L.; Ferreira, E. M.; Leite, H. G.; Cavallazzi, R. P. Critério técnico para determinação da idade ótima de mudas de eucalipto para plantio. Revista Árvore, v.29, p.947-953, 2005. http://dx.doi.org/10.1590/S0100-67622005000600014

Moura, A. R. C.; Montenegro, S. M. G. L.; Antonino, A. C. D.; Azevedo, J. R. G.; Silva, B. B.; Oliveira, L. M. M. Evapotranspiração de referência baseada em métodos empíricos em bacia experimental no estado de Pernambuco - Brasil. Revista Brasileira Meteorologia, v.28, p.181-191, 2013. http://dx.doi.org/10.1590/S0102-77862013000200007

Muçouçah, M. F. S.; Klar, A. E.; Muçouçah, F. J. Área foliar e evapotranspiração de *Callas* cultivadas em substrato em função do nível freático. Irriga, v.11, p.119-129, 2006.

Neves, W. S.; Oliveira, P. M.; Parreira, D. F.; Giaretta, R. D.; Costa, E. L. Importância do manejo da irrigação sobre a ocorrência de doenças de plantas. Informe Agropecuário, v.31, p.110-115, 2010.

Oliveira, G. X. S.; Coelho Filho, M. A.; Pereira, F. A. C.; Coelho, E. F.; Paz, V. P. da S.; Castro Neto, M. T. Relações entre transpiração máxima, evapotranspiração de referência e área foliar em quatro variedades de mangueira. Revista Brasileira de Fruticultura, v.31, p.20-27, 2009. http://dx.doi.org/10.1590/S0100-29452009000100005

Pereira, A. R.; Villa Nova, A. A.; Sediyama, G. C. Evapo(transpi)ração. Piracicaba: FEALQ, 1997. 183p.

Sabonaro, D. Z.; Galbiatti, J. A. Efeito de níveis de irrigação em substratos para a produção de mudas de ipê-roxo. Scientia Forestalis, v.1, p.95-102, 2007.

Santos, R. B.; Souza, A. P.; Silva, A. C.; Almeida, F. T.; Arantes, K. R.; Siqueira, J. L. Planejamento da pulverização de fungicidas em função das variáveis meteorológicas na região de Sinop-MT. Global Science and Technology, v.6, p.72-88, 2013. http://dx.doi.org/10.14688/1984-3801.v06n01a07

Silva, C. A. da. Desenvolvimento inicial de três espécies nativas do Cerrado em função de lâminas de irrigação e tamanhos de recipiente. Piracicaba: ESALQ, 2012. 181p. Tese Doutorado. http://dx.doi.org/10.11606/t.11.2012.tde-21122012-084813

Souza, A. P.; Mota, L. L.; Zamadei, T.; Martim, C. C.; Almeida, F. T.; Paulino, J. Classificação climática e balanço hídrico climatológico no estado de Mato Grosso. Nativa, v.1, p.34-43, 2013. http://dx.doi.org/10.14583/2318-7670.v01n01a07

Souza, A. P.; Silva, A. C.; Leonel, S.; Souza, M. E.; Tanaka, A. A. Evapotranspiração e eficiência do uso da água no primeiro ciclo produtivo da figueira 'Roxo de Valinhos' submetida a cobertura morta. Bioscience Journal, v.30, p.1127-1138, 2014.

Thebaldi, M. S.; Lima, L. A.; Colares, M. F. B.; Silva, A. C.; Lima, P. T. Uniformidade de aplicação de agua na irrigação de mudas de espécies florestais nativas produzidas em tubetes. Bioscience Journal, v.30, p.978-987, 2014.

Villa-Nova, N. A.; Pereira, A. R.; Barbieri, V. Evapotranspiration as a function of leaf area index and class A pan evaporation. Revista Brasileira de Agrometeorologia, v.4, p.35-37, 1996.