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Water and Radiation Use Efficiencies by *Erythrina velutina* and *Enterolobium contortisiliquum* Under Different Water Conditions

Yara Panta de Araújo[1]
Luciana Sandra Bastos de Souza[1]
Thieres George Freire da Silva[1]
Magna Soelma Beserra de Moura[2]

Abstract

This study investigated the water and radiation use efficiencies by *Erythrina velutina and Enterolobium contortisiliquum* under four water regimes. The experiment was carried out in the municipality of Serra Talhada, PE, Brazil. The experimental design was completely randomized with a 2 x 4 factorial arrangement and three replications. The water regimes were imposed from water replenishments based on the reference evapotranspiration (25, 50, 75 and 100% ET0). Water and radiation use efficiencies were calculated to the 120 days of growth. *E. velutina* showed a greater accumulated dry biomass (4.89 g pl^{-1}) than *E. contortisiliquum* (2.22 g pl^{-1}). The 75% ET0 water regime can be adopted without damage to the growth of both species. *E. velutina* was more efficient in the conversion of water (0.42 g l^{-1}) and radiation in dry biomass (0.028 g MJ^{-1}), indicating high environmental resilience, which is important features to choose species more adequate for reforestation activities.

Keywords: Caatinga, radiation use efficiency, water use efficiency.

1. INTRODUCTION

Seasonally dry tropical forests (SDTF) have peculiar morphophysiological mechanisms that give them resilience to adverse environmental conditions and great importance in the terrestrial carbon balance (Aragão et al., 2019). However, studies on the morphophysiological aspects and establishment of SDTF species are scarce and incipient (Dexter et al., 2018). This information is essential for the understanding of their relationship with abiotic factors (Trovão et al., 2007).

In Brazil, the SDTF is represented by the *Caatinga*. Such forest encompasses the vegetation that covers the semi-arid region (Queiroz et al., 2019). The Caatinga has approximately 912,529 km^2 (SILVA et al., 2017) and is subject to high radiation, high temperatures (23 – 27°C) and low relative humidity (60%), thus resulting in high atmospheric demand, which combined with the poor distribution of rainfall in space and time (300 – 800 mm year^{-1}) (Alvares et al., 2013; Alvalá et al., 2019), implies a negative water balance (Moura et al., 2007; Alvalá et al., 2019), which limits the development of the plants.

The Caatinga is composed of species adapted to environmental stress conditions, with leaves converted into thorns, some with photosynthesizing stems and reduction of leaf area by deciduous to decrease transpiration (Silva et al., 2004). Despite all those facts, in the early stages of growth, when seedling survival is conditioned by seed germination capacity and root system deepening (Figueirôa et al., 2004), the occurrence of water deficit can be lethal.

Studies carried out during the early development of the species are extremely useful because of their susceptibility to variations in the environment over the establishment. The information generated is essential for the creation of more efficient strategies in the production of seedlings, the understanding of the maintenance of the forests, and can also serve as the basis for the execution of reforestation activities (Lenhard et al., 2010).

The tolerance of the species to the environment can be studied by the calculation of indicators of use efficiency of natural resources such as water and radiation. In the first case, the water use efficiency allows us to understand the

[1] Universidade Federal Rural de Pernambuco (UFRPE), Serra Talhada, PE, Brasil

[2] Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Petrolina, PE, Brasil

water conversion capacity in biomass (Geerts & Raes, 2009; Silva et al., 2011); in the second case, the radiation use efficiency helps to understand the efficiency of the plants in absorbing and producing photoassimilates for the production of biomass (Battacharya, 2019). These two indicators can vary according to the leaf area index, height, age, and leaf arrangement of the plant (Battacharya, 2019).

Efficiencies in the use of water and radiation help to understand the plant responses to environmental stresses and selection of more adapted species, besides being key parameters in growth models, ecosystem productivity and among other applications (Silva et al., 2014; Teixeira et al., 2015).

Efficiencies of water and radiation use have been studied extensively for crops and are poorly exploited for native species (Souza et al., 2015). The species *Enterolobium contortisiliquum* (Vell.) Morong and *Erythrina velutina* Willd. belong to the Fabaceae family (Lima, 2019; Morim, 2019), which has an extensive occurrence in the Caatinga domain. The studied species present ecological and economic importance, and fast growth, desirable characteristics for the use in reforestation programs in degraded areas (Melo et al., 2008). Additionally, knowledge of how they use natural resources such as radiation and water can be useful for the preservation of ecosystem services in the Caatinga. This study investigated the water and radiation uses efficiencies by *Enterolobium contortisiliquum* and *Erythrina velutina* submitted to different water availability conditions.

2. METHODOLOGY

The experiment was conducted in a nursery covered with commercial shadow cloth located in the Academic Unit of Serra Talhada (7°57'S; 38°18'O; 499 m) of the Universidade Federal Rural de Pernambuco, municipality of Serra Talhada, state of Pernambuco. The experimental period was from June 7 2018 to October 5 2018. The climate of the region is semi-arid according to the classification of Köppen, characterized by average temperatures around 26°C, relative humidity of 63% and intense solar radiation incidence (Pereira et al., 2015). The annual rainfall is 642 mm year^{-1}, most of it occurring in four months (Pereira et al., 2015; Alvalá et al., 2019).

Atmospheric conditions were monitored using a meteorological station owned by the National Institute of Meteorology (INMET - http://www.inmet.gov.br), located 300 m from the experiment area over the experimental period. Average hourly data were obtained from the following meteorological elements: average air temperature (T, °C), air relative humidity (RH, %) (Figure 1a), rainfall (mm day^{-1}), and solar radiation (MJ m^{-2}d^{-1}) (Figure 1b). During the experiment period there was no need control of the rainfall due to low occurred events and the protection promoted by nursery (Figure 1b).

This information was converted into daily averages over time. In addition, the experiment was conducted when average temperatures were around 25.5°C, with minimum and maximum values of 22.5°C and 29.0°C, respectively. Air relative humidity ranged from 35% to 70%, with an average of 51%. Also, a high solar radiation index (mean of 23.7 MJ m^2 day) and low rainfall volumes were observed, with a total accumulated of 12 mm during the experimental period.
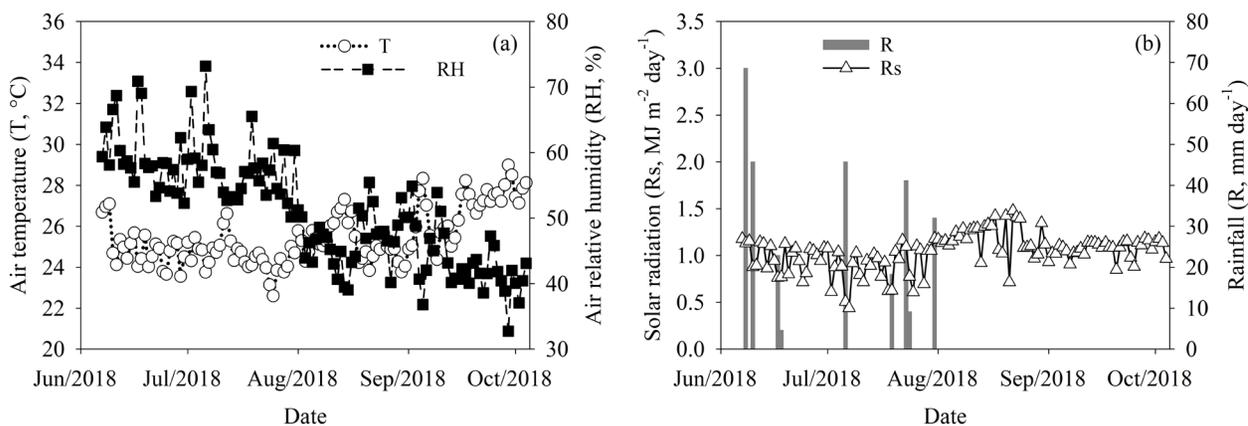
Figure 1. Temperature and air relative humidity (a), solar radiation and daily rainfall (b) in the municipality of Serra Talhada, state of Pernambuco over the experimental period.

The soil used in the experiment had its physical characteristics determined using samples were randomly obtained at the 0-20 and 20-40 cm depths (Table 1).

Table 1. Physical attributes of the soil used in different depths (0-20 and 20-40 cm), in the municipality of Serra Talhada, state of Pernambuco.

Depths	ρs	ρp	Φt	Total sand	Silt	Clay
cm	kg dm^{-3}		%		g kg^{-1}	
0 – 20	1.30	2.5	48.3	815.2	128.4	56.4
20 – 40	1.32	2.5	47.9	828.5	134.3	37.1

ρs = Soil density; ρp = Particle density; φt = Total porosity of the soil.

Pots with 21.5 cm in diameter (5 L) were used (Figure 2). They were filled with soil sieved in 2 mm mesh and 200 mL worm humus. Subsequently, the pots were placed in the field capacity using a volume of water equivalent to 1250 ml in each pot.

The experiment was conducted in a completely randomized design, in a 2 x 4 factorial arrangement, with two species and four water regimes, in three replicates. The species *E. contortisiliquum* and *E. velutina* were used. Their seeds were initially submitted to scarification with wood sandpaper to break dormancy and seeded in the pots. The water regimes were imposed from the water replenishment based on the fractionation of the reference evapotranspiration (ET0): 25% (7.4 L); 50% (10.3 L); 75% (13.3 L) and 100% (16.3 L). In the first 34 days after sowing (DAS), daily replenishment was also executed for all plants based on 100% ET0, calculated using the Penman-Monteith equation (Equation 1) standardized by FAO56 (Allen et al., 1998), using the meteorological information obtained during the experiment:

$$ET0 = \frac{0.408\Delta(Rn - G) + \gamma\left(\frac{900}{t+273}\right)u_2(e_s - e_a)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \quad (1)$$

where: ET0 - reference evapotranspiration (mm d^{-1}); Δ - slope of the saturation water vapor pressure curve (kPa °C^{-1}); Rn - surface radiation balance (MJ m^{-2} d^{-1}); G - sensible heat flux density in the soil (MJ m^{-2} d^{-1}); t – daily average air temperature (°C); u$_2$ - wind speed in 2 m height (m s^{-1}); es-water vapor saturation pressure (kPa); ea - partial pressure of water vapor (kPa) and γ - psychometric constant (kPa °C^{-1}).

During the experimental period, a campaign was made to obtain information on the biomass of the seedlings. In this case, three individuals of each treatment were obtained to the end of the experiment on October 5 2018. Those individuals had their organs separated and allocated in Kraft paper bags. These were properly identified and taken to a forced-air circulation oven at 60°C for about 72 h. The samples were then weighed using a 0.001-g scale (Model MARK 210A, Bel Engineering, Monza-MI, Italy) to obtain data on the root dry biomass (RDB, g pl^{-1}), dry leaf biomass (DLB, g pl^{-1}), stem dry biomass (SDB, g pl^{-1}), aerial part dry biomass (APDB = DLB+SDB, g pl^{-1}), total dry biomass (TSD = RDB + DLB + SDB, g pl^{-1}) and DLB/TDB and RDB/TDB partitions.

Water use efficiency was obtained by the ratio between total dry biomass and total volume of water applied (Geerts & Raes, 2009; Silva et al., 2011) (Equation 2).

$$WUE = \frac{TDB}{V} \quad (2)$$

where: WUE is the water use efficiency (g l^{-1}), TDB is the total dry biomass (g pl^{-1}), and V is the total volume of water applied (l^{-1}).
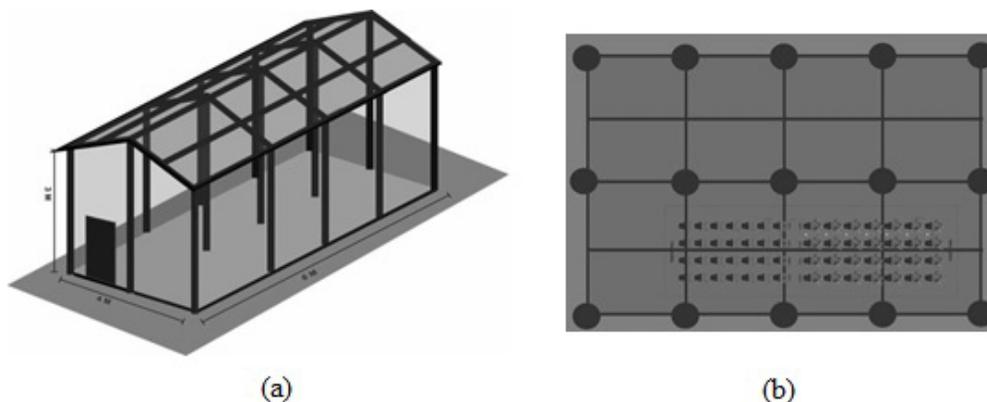
Figure 2. Diagrammatic representation of the nursery (a), construction drawing with plant arrangement on the sketch (b), in the municipality of Serra Talhada, state of Pernambuco (Elaborated by Nogueira, F. B.).

Over the experiment, photosynthetically active radiation (PAR) was measured at different positions inside ($PAR_{internal}$) and outside ($PAR_{external}$) of the nursery. Four readings were conducted, one above (PAR_{Ap}) and the other three readings at different positions below (PAR_{Bp}) the plant. For this purpose, the AccuPAR (Decagon Devices, Inc., Pullman, Washington, USA) ceptometer was used and the value of the photosynthetically active radiation was obtained through the average of the readings. Measurements were performed between 11 a.m. and 2 p.m., with intervals of 8 days, totaling 12 campaigns. This information was used to determine the intercepted photosynthetically active radiation (PARp), using the equations described by Gower (1999) (Equation 3).

$$PAR_p = 1 - \frac{PAR_{Ap}}{PAR_{BP}} \qquad (3)$$

Where PAR_{Ap} = photosynthetically active radiation above the plant (MJ m^{-2} d^{-1}), PAR_{Bp} = photosynthetically active radiation incident below the plant (MJ m^{-2} d^{-1}).

Data on PARp were used to adjust sigmoid equations in order to estimate their values for every day over the experiment as a function of DAS.

The $PAR_{external}$ data from the nursery were correlated with the global solar radiation data of INMET meteorological station, as reported by Caron et al. (2014), resulting in the following relation:

$$PAR_{external} = 0.48 \times Rg \qquad (4)$$

where: Rg = global solar radiation (MJ.m^{-2}.d^{-1}).

Radiation use efficiency (RUE, g MJ^{-1}) was obtained through the ratio between cumulative intercepted radiation (CIPAR) and total dry biomass during the experiment in each treatment using equation 5. The use of shadow cloth promoted a 45% attenuation of the $PAR_{external}$. Like, this the $PAR_{external}$ values were used for the calculation of the $PAR_{internal}$. The CIPAR for each species throughout the experiment was derived from the product between $PAR_{internal}$ and PAR_p.

$$RUE = \frac{TDB}{CIPAR} \qquad (5)$$

where: TDB is the total dry biomass (g pl^{-1}) and CIPAR is the cumulative intercepted radiation over the period (MJ m^{-2} day^{-1}).

The experimental data were submitted to the normality and homoscedasticity test, analysis of variance, and the means were compared by the test of Tukey at the 5% probability level. Regression tests were performed whenever it was needed.

3. RESULTS AND DISCUSSION

Significant differences were found for the species and, or, water regime factors at the 5% probability level for the following parameters: dry leaf biomass (DLB), stem dry biomass (SDB), total dry biomass (TDB), dry leaf biomass/total dry biomass ratio (DLB/TDB), stem dry biomass /total dry biomass ratio (SDB/TDB), total aerial part dry biomass (APDB) and water use efficiency (WUE). No interaction effect was found between the species and the water regime (p> 0.05) (Table 2). Therefore, regardless of the water regime, the species *Erythrina velutina* presented higher biomass accumulation in relation to *Enterolobium contortisiliquum*. In turn, the 75% ET0 allowed for greater growth independent of the species.

Table 2. Analysis of variance (ANOVA) for dry leaf biomass (DLB), stem dry biomass (SDB), root dry biomass (RDB), aerial part total dry biomass (APDB), dry leaf biomass - total dry biomass ratio (DLB/TDB), stem dry biomass - total dry biomass ration (SDB/TDB), root dry biomass - total dry biomass (RDB/TDB) and water use efficiency (WUE) in relation to the effects of the species and water factors. SS: sum of squares; MS: mean square; F: statistic of test F and P represents the significance.

Source of variation	Variables	SS	MS	F	P
	DLB	2.13	2.13	16.49	0.000909**
	SDB	56.25	56.25	145.15	0.000000**
	RDB	0.25	0.25	2.99	0.103253ns
	APDB	36.48	36.48	72.07	0.000000**
Species	TDB	42.80	42.80	83.15	0.000000**
	DLB/TDB	0.96	0.96	148.27	0.000000**
	SDB/TDB	1.32	1.33	339.05	0.000000**
	RDB/TDB	0.03	0.030	3.93	0.064485ns
	WUE	0.34	0.334	112.96	0.000000**

Table 2. Continued...

Source of variation	Variables	SS	MS	F	P
Blade	DLB	2.17	0.72	5.60	0.008063**
	SDB	7.74	2.8	6.66	0.003975**
	RDB	1.35	0.45	5.32	0.009735ns
	APDB	17.35	5.78	11.41	0.000299**
	TDB	28.23	9.41	18.28	0.000020**
	DLB/TDB	28.23	9.41	18.28	0.000020**
	BSC/TDB	0.02	0.01	2.00	0.154364ns
	BSR/TDB	0.01	0.004	0.60	0.0622404ns
	WUE	0.03	0.009	3.09	0.056703ns
Blade X Species	DLB	0.24	0.78	0.60	0.622544ns
	SDB	2.85	0.95	2.45	0.100892ns
	RDB	0.90	0.30	3.57	0.037761ns
	APDB	2.61	2.87	1.72	0.202797ns
	TDB	1.42	0.47	0.92	0.452897ns
	DLB/TDB	0.47	0.01	2.43	0.102888ns
	SDB/TDB	0.01	0.004	1.19	0.343176ns
	RDB/TDB	0.07	0.024	3.24	0.050121ns
	WUE	0.01	0.003	1.26	0.320732ns

**significance at 5%, ns not significant.

The effects of the species (Figure 3a-f) demonstrated that *E. contortisiliquum* had 57% higher dry leaf biomass (DLB) production than *E. velutina* (Figure 3a). This behavior may be directly associated with the leaf morphology of each species, as *E. velutina* displays simple leaves (and in smaller numbers), while *E. contortisiliquum* exhibits compound leaves with faster development. According to Oliveira et al. (2007), the leaves are the structures responsible for the production of most of the carbohydrates necessary for the growth of the plant. In this situation, the mass gain of the plant depends on its capacity to convert natural resources into biomass.

The dry stem biomass (DSB) showed an inverse behavior to that observed for DLB between the species. It can be seen that *E. velutina* displayed 83% more SDB than *E. contortisiliquum* (Figure 3b). At this stage of growth, the stem of *E. velutina* showed to be more robust, therefore demonstrating that this species invested more in a support structure when compared to *E. contortisiliquum* (DSB/TDB, Figure 3e). Santos et al. (2013) mention that the increment in the DSB/TDB partition can occur due to the contribution of defense structures of the plant, as is the case of aculeus. As a consequence, a more significant investment was observed in the aerial part biomass (APDB) and total dry biomass (TDB) for *E. velutina* in relation to *E. contortisiliquum* (Figures 3c-d, respectively). *E. velutina* showed about twice the capacity of TDB accumulation when compared to *E. contortisiliquum* (Figure 3d). Concerning the accumulation of dry biomass by the roots (RDB), no differences were observed between

the species. Different results were observed by Barbosa et al. (2013) analyzing the initial growth of Caatinga species. They noticed that *E. contortisiliquum* exhibited higher RDB when compared to *E. velutina*, *Piptadenia stipulacea*, and *Anadenanthera macrocarpa*.

The DLB, SDB, APDB, TDB and the DLB/TDB partition increased as water regime was incremented, therefore, reaching higher magnitudes in the water replenishment of 100% ET0 (Figure 4a-e). However, except for TDB (Figure 4d) no statistical difference was found between the conditions of 50% ET0, 75% ET0 and 100% ET0 for most variables; that is, the smallest accumulated values of biomass were verified in the 25% ET0 water regime. But accumulated values of biomass in the 25% ET0 water regime did not differ from the 50% ET0 water regime. Like this, the 75% ET0 water regime can be adopted without damage to the growth of both species.

The 25% ET0 blade reduces the APDB accumulation by 59% when compared to the 100% ET0 water regime (Figure 4c). Santiago et al. (2001) indicate that plants under water stress establish strategies to reduce the loss of water to the atmosphere. Among those mechanisms, the stomatal closure and leaf wilting can be mentioned. They affect photosynthesis, therefore directly affecting plant growth. When analyzing the growth of *Hymenaea courbaril* seedlings, Nascimento et al. (2005) observed that the reduction of soil water availability to levels equivalent to 25% of the field capacity (FC) decreases the dry mass of leaves, stem, and total of the plant by 77%, 71%, and 70%, respectively
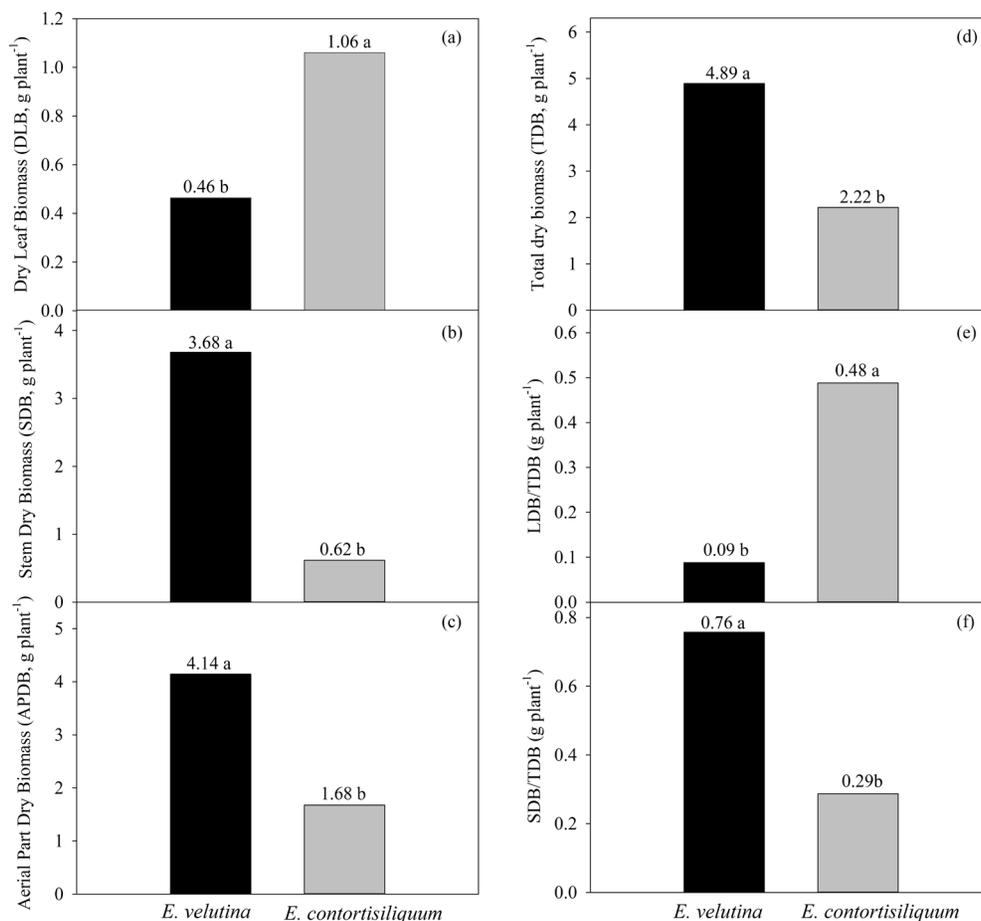
Figure 3. Dry leaf biomass - DLB (a), stem dry biomass - SDB (b), aerial part dry biomass (c), total dry biomass - TDB (d), dry leaf biomass/total dry biomass (DLB/TDB) (e) and stem dry biomass/total dry biomass (SDB/TDB) (f) for *Erythrina velutina and Enterolobium contortisiliquum*, regardless of water regime, in the municipality of Serra Talhada, state of Pernambuco.

The TDB in the 50% ET0 water regime presented an engagement to the accumulation of the biomass by 26% in relation to 100% ET0 (Figure 4d) while this reduction was 60% in the 25% ET0 water regime. A smaller contribution of the roots to the TDB occurred in both cases when compared to APDB. In spite of this, *E. contortisiliquum* invested more in the root system (25% TDB) than *E. velutina* (19% TDB). Santiago et al. (2001) performed a work using *Mimosa caesalpiniifolia* grown in water stress relative to field capacity percentages (FC) of 25% FC - severe stress and 50% FC - moderate stress. These authors observed that the increase in stress severity results in significant reductions in plant growth.

The species *E. contortisiliquum* and *E. velutina* showed significant differences in the water use efficiency; however, they were not affected by the water regimes, therefore, showing that these species exhibit high resilience in the early stages, with high capacity of water use. *E. velutina* was more efficient in the conversion of water to dry matter over the analyzed period, which can guarantee the maintenance of this species in the environment for a longer period of time. The plants that present greater efficiency of water use are able to show better development and establishment in places with low water availability (Pimentel, 2004). Souza (2014) studied the water use efficiency (WUE) based on photosynthesis and transpiration (P/T) in adults of five species and found that a slight increase in water deficit resulted in significant increases in the WUE. Similar results were observed by Gulías et al. (2002) for species native to the Mediterranean.

The greater WUE showed by *E. velutina* may also be associated with its ability to convert radiation into biomass (Figures 5a). The ability of the plant to absorb radiation is a reflection of its leaf area and distribution geometry (Plénet et al., 2000). In this case, the leaf arrangement of *E. velutina*, with simple leaves and inserted perpendicularly to the stem, allowed greater interception of the photosynthetically active radiation. The

presence of leaflets in *E. contortisiliquum* promotes greater transmittance of the radiation, which results in a reduction of 47% of the RUE in relation to *E. velutina*. However, intrinsic physiological and anatomical mechanisms of both species (i.e. photosynthetic rate, stomatal conductance, and stomata density), which were not measured here, may also have contributed to these results, since they modify the capacity of biomass accumulation by plants.

The low water regime reduces WUE of both species (Figure 5b). The occurrence of severe water deficit induced the plants to adjust the morphology such as leaf senescence to overcome environmental conditions (Figure 4a). According to Matos et al. (2018), in a study using *Tectona grandis* species, this behavior is typical of native species as an alternative for survival in the environment. The leaf reduction decreased the transpiring surface but did not compromise the WUE as it was not affected by the water regimes. The effect of water stress on the WUE was completely tied to DLB, so that the smaller the applied water depth, the lower the DLB, and the smaller the magnitude of the WUE.
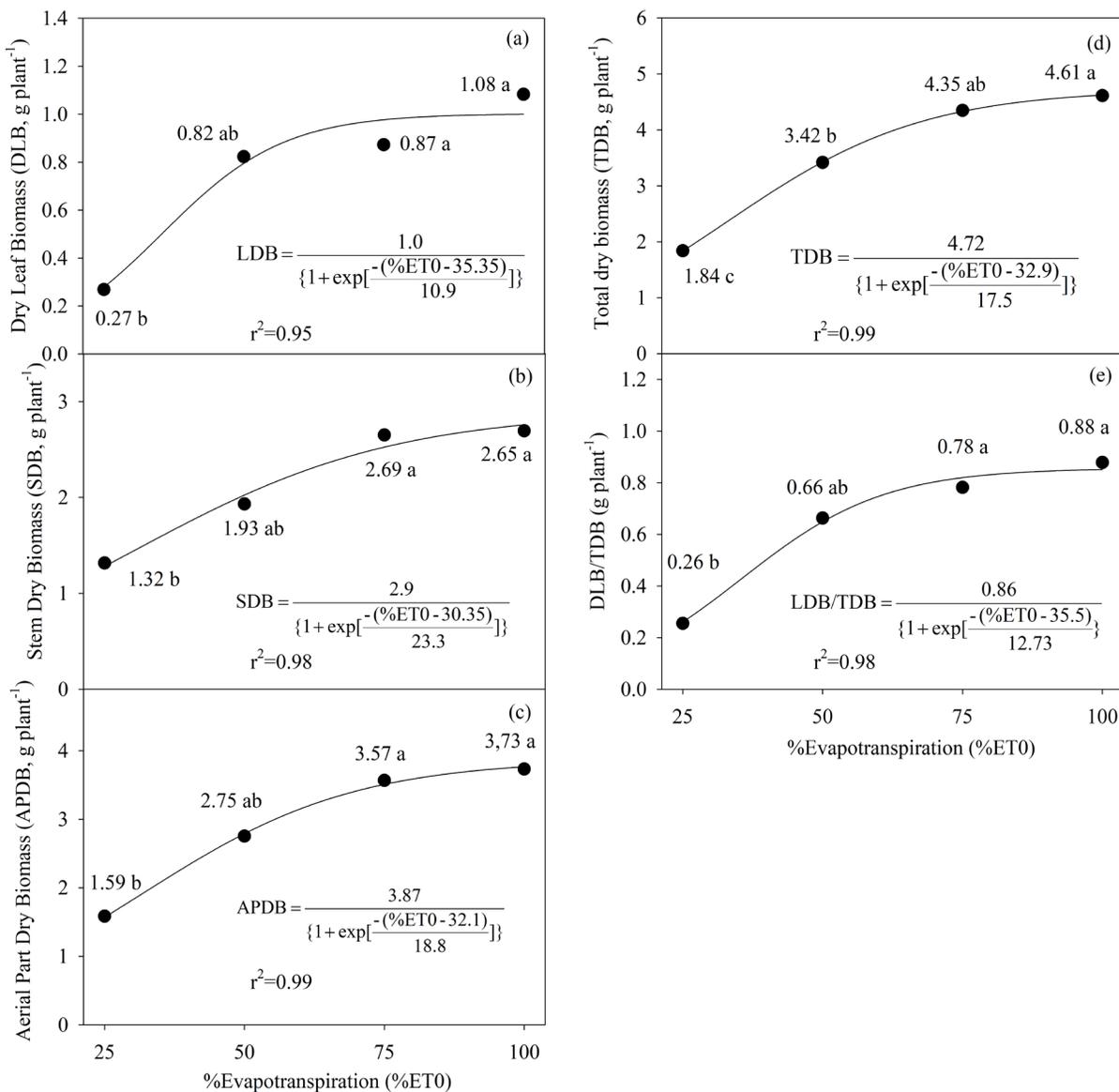
Figure 4. Dry leaf biomass - DLB (a), stem dry biomass - SDB (b), aerial part dry biomass - APDB (c), total dry biomass - TDB (d), dry leaf biomass/total dry biomass (e) according to the water regime (%ET0) for *Erythrina velutina e Enterolobium contortisiliquum*, regardless of species, in the municipality of Serra Talhada, state of Pernambuco.
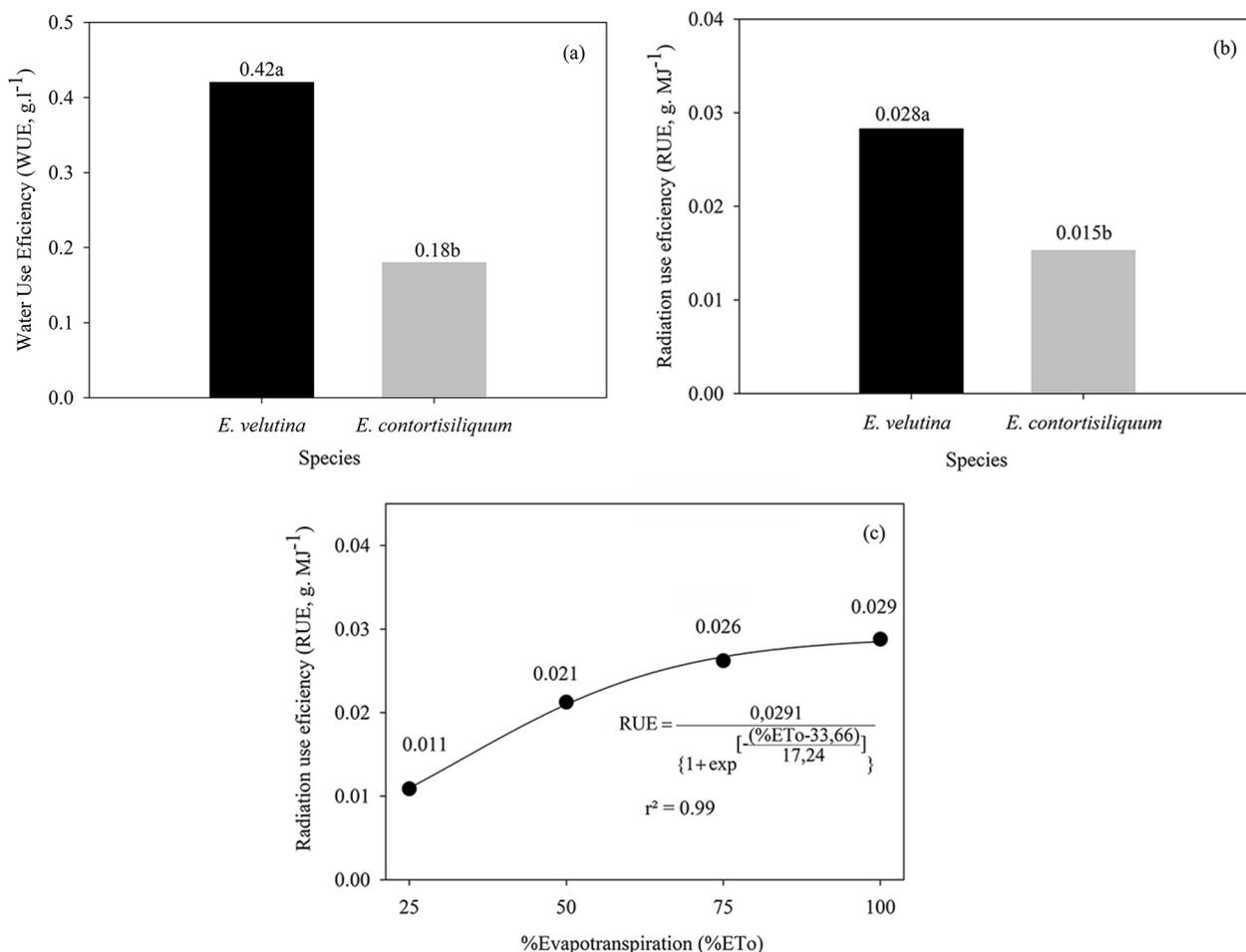
Figure 5. Water and radiation use efficiencies in relation to *Erythrina velutina* and *Enterolobium contortisiliquum* (A and B), regardless of water regime, and radiation use efficiency for different water regime (C), regardless of species, in the municipality of Serra Talhada, state of Pernambuco.

4. CONCLUSIONS

In the first 120 days of growth, regardless of water regime, *E. velutina* showed a greater accumulated dry biomass (4.89 g pl^{-1}) than *E. contortisiliquum* (2.22 g pl^{-1}). The 75% ET0 water regime can be adopted without damage to the growth of both species. *E. velutina* was more efficient in the conversion of water (0.42 g l^{-1}) and radiation in dry biomass (0.028 g MJ^{-1}), indicating high environmental resilience, which is important features to choose species more adequate for reforestation activities.

SUBMISSION STATUS

CORRESPONDENCE TO

Thieres George Freire da Silva

Universidade Federal Rural de Pernambuco (UFRPE), Avenida Gregório Ferraz Nogueira, S/N, Bairro José Tomé de Souza Ramos, CEP 56.909-535, Serra Talhada, PE, Brasil.

E-mail: thieres_freire@yahoo.com.br

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