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The Correlation of Rubber Tree Ecophysiology (*Hevea brasiliensis* Willd. Ex A. Juss) for the Promotion of Latex Production

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ABSTRACT

The water use efficiency is intrinsic to each plant species and is influenced by meteorological variables, as well as by water available in the soil. As one of the largest crops of forest species to produce non-timber products, there is the extraction of rubber tree (*Hevea brasiliensis*), a native species from Brazil, recognized worldwide for its natural rubber production. Thus, to contribute to the knowledge of the ecophysiology of this species to promote its higher productivity, this research aimed to characterize, quantify and compare the ecophysiological behavior (photosynthesis, transpiration, stomatal conductance, water use efficiency) in the function of environmental variables and soil water availability. With the infrared gas analyzer, monitoring of the ecophysiological variables was performed on the hour scale, on healthy and expanded leaves of potted seedlings, and the leaf water potential (Ψpd) was obtained by the Scholander chamber. It was verified that the lower leaf water potential, also is the smaller the gas exchanges. Photosynthesis, transpiration and stomatal conductance showed a 56%, 78% and 69% decrease in the conditions with higher water potential for the lowest. Under conditions of leaf water potential up to -1.0 MPa, the ecophysiological behavior had a greater influence of the vapor pressure deficit, whereas, in Ψpd ≤ -1,1 MPa, the photosynthetically active radiation was better correlated, being still in this range of Ψpd, the greater efficiency of water use.

INTRODUCTION

The ecophysiology study of the native species brings a better understanding of the ecological relationships that govern tropical forests. Each species has intrinsic characteristics regarding its growth and development, which is a consequence of physiological processes influenced by environmental conditions (1,2). As one of these factors, water deficiency is considered the main environmental factor that negatively limits plant growth (3–6).

Among the native forest species in Brazil used commercially to obtain non-wood products by extraction, is the rubber tree (*Hevea brasiliensis* Willd. Ex A. Juss), recognized worldwide as the main natural rubber source. According to (7), Brazil became the world's largest producer of natural rubber and supplied international trade from 1879 to 1912. This fact brought wealth and development to Manaus, Belém and Rio Branco cities and Acre colonization. (7).

In 2017, the sector generated R$ 590 million in the São Paulo state, the largest Brazilian producer, responsible for 58% of the national volume. The country today produces around 180 thousand tons of natural rubber. It gives to Brazil the title of the largest natural rubber producer in Latin America (8). There are 90 thousand hectares that generate about 15 thousand jobs (9).

Hevea brasiliensis is a heliophite plant, efficient in converting light into carbohydrates, and grows well in high light, humidity and temperature conditions. For the plant to produce látex, it uses a substrate dependent, in the short term, on photosynthesis (10).

Thus, the latex production by rubber tree may present a seasonality pattern as a result of photosynthetic and, in turn, the soil water availability (11–14). Since photosynthesis is related to transpiration and water consumption, these physiological processes interfere the látex production. So, it makes it essential to know the *H. brasiliensis* ecophysiological behavior under different environmental conditions. Studies on the commercial forest species ecophysiology have been extensively carried out with *Eucalyptus* sp. These studies seeks to know the ecophysiological behavior due to climatic variables to obtain greater cellulose productivity (15–18).

The objetive of this work was to characterize, quantify and compare the ecophysiological behavior of the rubber tree, *Hevea Brasiliensis*, in the function of environmental variables and soil water availability. This knowledge could provide information about this specie and enable its greater use in the productive latex chain.

MATERIAL AND METHODOLOGY

The experiment was conducted in an experimental site at Federal University of São Carlos, Sorocaba campus-São Paulo, Brazil, at geographical coordinates 23º34'S and 47º 31'W and mean altitude of 580 m. The climate in the region is classified as Cwa, dry/hot temperate climate with hot summer (19); the mean annual temperature in the region reaches 22ºC and the mean annual rainfall is 1,311 mm (20).

The rubber tree (*Hevea brasiliensis* Willd. Ex A. Juss) is a latent forest species of the Euphorbiaceae family and occurs in the Amazon region, along rivers and floodplains, being considered a pioneer semideciduous species. (21).

Three (3) rubber trees were monitored from December 2017 to June 2018. The trees were transplanted into 100-dm^3 pots, which had holes in their lateral and lower faces to enable better root aeration and excess water drainage. The same substrate was used in all pots; it comprised fertilized soil and chicken manure. The in-pot monitoring allowed controlling water available in the soil in order to measure variations in leaf water potential throughout the monitored period. Water would only be replenished through irrigation or rainfall; thus, roots were not able to get water from subsoil layers.

Predawn leaf water potential (Ψ_{pd}) was divided in 3 classes: (1) 0 to -0.50 MPa, (2) -0.51 to -1,0 MPa, and (3) -1,01 to 1,50 MPa. This variable was measured in Scholander pressure chamber (22) model 3035 (Soil Moisture Equipment Corp., USA). This method enables estimating cells' ability to retain water through the pressure exerted (MPa) by an inert gas. The lesser water in the plant, the greater the pressure required to exude it. Therefore, three branches per individual were simultaneously collected before sunrise, when stomata were still closed, a fact that enables plants to be in equilibrium with the water potential in the soil (23).

Photosynthesis (A), stomatal conductance (Gs) and transpiration (E) were monitored at leaf scale: four healthy and fully expanded leaves located in the mid third of the crown and exposed to solar radiation were selected for each individual. Hourly readings were performed throughout the day, from 7 am to 4 pm (solar time), with the aid of the Infrared Gas Analyzer (IRGA) (LC-PRO, ADC, BioScientific Ltda., UK), which also provided information about photosynthetically active radiation (Qleaf) at each measurement time.

In order to understand the ecophysiological behavior of the individuals as a function of environmental characteristics, complementary climatic data of temperature and relative humidity were obtained from the Sorocaba Automatic Surface Observation Meteorological Station. Thus, for each day, the vapor pressure deficit of the atmosphere (VPD) was calculated, on the hourly scale, using the Tetens equation (24):

$$VPD = es - ea, \quad (1)$$

The saturation pressure of vapor (es) was calculated using the following equation:

$$es = 0.6108 * 10\ 7.5*Tar / 237.3 + Tar \quad (2)$$

where Tar corresponds to the air temperature in ° C and s in kPa.

The partial vapor pressure (ea) was obtained by the following equation:

$$ea = RH * es/100, \quad (3)$$

where RH is the relative humidity of the place, expressed in %.

Photosynthesis (A) / transpiration (E) ratio was calculated to obtain information about water use efficiency (WUE) in the investigated species - this ratio corresponds to the carbon unit fixed per transpired water unit.

Analysis of variance was applied to measure the A, E and WUE in order to enable the comparative analysis of means between Ψpd. Significant means were compared to each other through Tukey test in the Minitab 14.0 software. Pearson's correlation test was also performed between the variables ecophysiological and environmental according to Ψpd.

RESULTS

In general, the daily mean values of the ecophysiological variables of rubber trees were higher in less restrictive water potentials (Table No.1). Regarding the environmental variables, it was found that there was no statistical difference between the environmental conditions to which the rubber tree individuals were submitted to carry out this study. Therefore, we can consider that the relative humidity together with the air temperature (VPD), as well as the photosynthetically active radiation (Qleaf), were similar throughout the study period.

Photosynthesis showed a 56% decrease in the average values observed between classes 1 (0 to -0.5 MPa) and 3 (-1.01 to -1.50 MPa) of water potential. In class 3, E and Gs were 69% and 78% lower than class 1, respectively.

Table No. 1. Mean Photosynthesis (A), Transpiration (E), Stomatal conductance (Gs), photosynthetically active radiation (Qleaf) and vapour pressure deficit (VPD) in function of predawn leaf water potential class (Ψpd). Mean ± standard error of the mean.

Ecophysiological variables	**Class 1 (0 a -0.5 MPa)**	**Class 2 (-0.51 a -1.0 MPa)**	**Class 3 (-1.01 a -1.5 MPa)**
A (µmol.m-^{2}.s^{-1})	8.75 ± 0.99 a	5.76 ± 0.79 a	3.79 ± 0.54 b
E (mmol.m-^{2}.s^{-1})	4.55 ± 0.74 a	3.25 ± 0.79 ab	1.43 ± 0.20 b
Gs (mol.m-^{2}.s^{-1})	0.18 ± 0.04 a	0.16 ± 0.02 ab	0.04 ± 0.01 b
WUE (µmol.mmol^{-1})	2.19 ± 0.35 a	1.91 ± 0.38 b	2.71 ± 0.29 c
Qleaf (µmol.m-^{2}.s^{-1})	1439 ± 231 a	1020 ± 252 a	830 ± 162 a
VPD (kPa)	1.40 ± 0.29 a	1.03 ± 0.26 a	1.04 ± 0.22 a

Averages followed by the same letter in the lines do not differ by Tukey test at 5% probability.

When analyzing the daily course, it is observed that, mainly A and E, tend to follow Qleaf (Figure No. 1A, 1B, 1D), even though the amplitude is different by Ψpd class. As water restriction occurs in the soil, this relationship is less evident.

As for VPD, it showed an increasing trend over the days, reaching its maximum value around 2.5 kPa at 4 pm (Figure No. 1E), however, regardless of the Ψpd class, the ecophysiological variables did not show a trend to follow this up. environmental variable. On the other hand, it can be seen in Table No. 2 that the relationship between ecophysiological variables and VPD is inversely proportional, with the exception of the E x DPV ratio in class 3.

In classes 1 and 2, a greater correlation between ecophysiological variables and VPD was observed, with the exception of E x Qleaf for class 2 (Table No. 2). For class 3, Qleaf appears to have the greatest influence on gas exchange, where the greatest correlation was between E and Qleaf. This behavior suggests that, in Ψpd to -1.0MPa conditions, VPD can provide a greater latex production. Above that Ψpd, Qleaf seems to promote greater impulse.

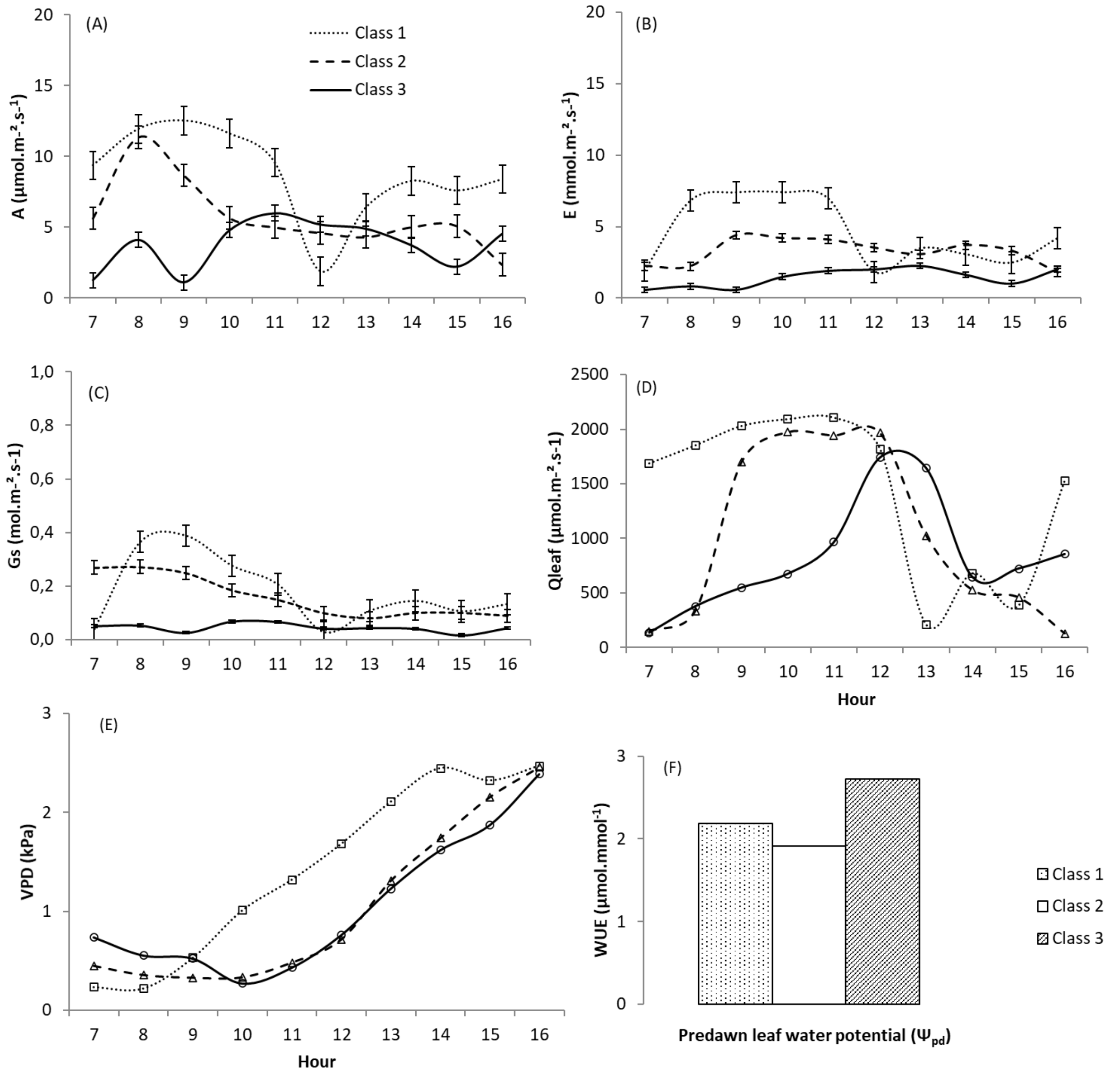

Figure No. 1. Hourly mean values of (A) Photosynthesis, A, (B) Transpiration, E, (C) Stomatal conductance, Gs, (D) Photosynthetically active radiation, Qleaf, (E) Vapor Pressure Deficit, DPV and (F) Water use efficiency, WUE of rubber tree seedlings (*Hevea brasiliensis*) by predawn leaf water potential class (Ψ_{pd}).

Table No. 2. Simple correlation between ecophysiological variables (photosynthesis, A; transpiration, E; stomatal conductance, Gs) and environmental variables (photosynthetically active radiation, Qleaf; vapor pressure deficit, VPD) in different predawn leaf water potential class (Ψ_{pd}).

Ecophysiological variables	Ψ_{pd} (Mpa)		
	0 a -0.50	-0.51 a -1.00	-1.01 a -1.50
A x Qleaf	0.35	0.01	0.39
E x Qleaf	0.74	0.61	0.69
Gs x Qleaf	0.56	0.01	0.28
A x VPD	-0.44	-0.43	-0.06
E x VPD	-0.75	-0.28	0.33
Gs x VPD	-0.78	-0.56	-0.18

DISCUSSION

Transpiration reduction is a highly relevant mechanism for plant survival in water scarcity conditions (25). (26), observed that an efficient protection mechanism in *Jatropha curcas*, which allowed this species to survive in drought conditions. (27) also found a decrease in the values of A, E and Gs in rubber tree cultivars, according to the soil water restriction. (28) observed that the rubber tree plants showed higher values in conditions with greater water potential, both for photosynthesis and for stomatal conductance. (29) when studying young rubber trees, noted that, under low water availability, regardless of the treatment adopted, photosynthesis, transpiratory rate and stomatal conductance were significantly decreased.

Young rubber trees, in field conditions, in the dry period showed a decrease of 34% in the photosynthetic rate, 44% in transpiration and 40% in the values of stomatal conductance (30). Equivalent values were found in the studies by (31), in which there was a decrease in the photosynthetic rate of 32% and 22%, transpiration of 44% and 38% and stomatal conductance of 29% and 17% in the two different cultivars studied between rainy and dry periods.

In contrast, greater water availability contributed to higher photosynthetic rates, due to less stringent stomatal control, which also influenced the higher transpiration values in this condition (32–34). The availability of an adequate water amount allowed individuals of *Erythroxylum simonis* to also exhibit high transpiration rates (6).

Under greater water restriction conditions (class 3), even with high Qleaf and VPD, the E, A and Gs rates were reduced throughout the day, showing stomatal closure (Gs) as a water loss control. This behavior was also verified by (28,35).

The knowledge of the relationship between water, environmental and ecophysiological variables can contribute to the choice of a better management and cultivation site. An example of application the forest species ecophysiology knowledge is the study developed by (35), who studied the ecophysiological behavior of two *Eucalyptus* sp clones and observed that one of the clones had greater ecophysiological potential under higher VPD conditions, while the other was more driven by Qleaf. With that, they were able to suggest the management and the planting of each one of them according to the environmental conditions.

The leaf water potential is one of the most important factors that affect the stomata functioning. Under the conditions presented in this study, even in the most restrictive water potential situation (-1.01 to -1.50 MPa), total stoma closure was not observed (Gs = 0 $mol.m^{-2}.s^{-1}$). In the study of (27), under field conditions and water potential values close to -1.70 MPa, the stomata also did not close completely. However, in young rubber plants, (36) reported total closure of stomata under Ψpd = –1.3 MPa, which occurred after 13 days without irrigation.

Values close to -1.5 MPa were observed by (37) as limiting the stomatal closure of young seedlings. (38) also found that, for rubber trees kept in a greenhouse, with increased water deficit, total stoma closure occurred without net photosynthesis gain. In the study of (39) when the water potential reached critical values, approximately -2.0 MPa, the wilting and falling of the rubber tree leaves was observed.

Water stress, by promoting stomatal closure, reduces the CO_2 internal concentration (Ci) in the leaf mesophyll, with a consequent photosynthesis reduction. In this sense, water availability and Ci can represent limiting factors for photosynthesis, especially due to the gas conduction restriction in the leaf (40,41).

Analyzes of the transient chlorophyll fluorescence “a” carried out by (39) showed that water deficiency compromised fundamental processes in the photochemical phase of photosynthesis, reducing the light energy use in two varieties of *Hevea brasiliensis*.

Since the gas exchanges of the rubber tree seedlings studied showed significant differences between the different water potentials, it was evident that the ecophysiology responded to the water changes, since the environmental conditions were similar between the Ψpd classes.

The relationship between the photosynthesis and transpiration, since it relates the carbon amount fixed by the water lost amount, is an important indicator of water use efficiency (42). In this study, the average values of the WUE between the three classes showed that these were statistically different, whereas class 3 was 23% above class 1 (Figure No. 1F, Table No. 1). That is, in the greater water restriction, in this case, from -1.01 to -1.50, the rubber tree showed greater assimilation through photosynthesis (A) per unit of water. (35) also observed, in *Eucalyptus* sp, greater efficiency in the water use in situations of water restriction, despite this condition not being statistically different from more comfortable water potentials for that study.

Higher WUE values is commonly in plants with water stress, before the stomata are completely closed (14,43,44), as was observed in the present study.

The increase in the WUE in a drier period was also observed by (30) in young rubber tree plants in field conditions. (45) also found the same behavior in adult coconut palm plants (*Cocus nucifera*).

Thus, the stomatal closure of the studied rubber tree seedlings proved to be a defense strategy, by minimizing water loss through transpiration and helping to maintain the water content in the leaves, also improving the efficiency of water use (46). This physiological strategy to avoid excessive water loss through transpiration can be considered a mechanism that can provide leaf growth in drier seasons (47–49).

The latex produced by rubber trees contains 68% of water. So, water conditions are extremely important for this species, since it needs soil water for production (27). In one of the rubber tree cultivars studied by (12) the photosynthetic rate also decreased significantly and a 23% drop in dry rubber production was found. It means that the decrease in photosynthesis is accompanied by a decrease in latex production since the dry rubber content depends primarily on the photosynthetic efficiency (50).

Thus, according to (13), since that photosynthesis promotes rubber productivity by rubber, factors that govern photosynthesis can be used in the early selection of *Hevea brasiliensis* genotypes process for different environments. Therefore, it is necessary to know each species physiological response to water and soil conditions and climate, in order to provide greater latex production.

CONCLUSION

The results indicated that the leaf water potential influenced the ecophysiology of *Hevea brasiliensis*. In general, seedlings with less leaf water potential showed lower gas exchange rates. However, in conditions of leaf water potential up to -1.0MPa, the ecophysiological behavior starts to have a greater vapor pressure deficit influence, whereas in Ψpd less than -1.1 MPa, the photosynthetically active radiation was better correlated, being still the greater water use efficiency in this Ψpd range.

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