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Influence of Terrestrial Parameters on the Ecophysiological Composition of Young Plants Kahya Senegalensis in Saline Environment

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Abstract

This study aims at analyzing the behavior of young African mahogany plants in a saline environment, focusing on perceptions related to transpiration, photosynthetically active radiation and water potential. The experiment was conducted in drainage lysimeters, using different salinity levels of irrigation water. Environmental data, such as photosynthetically active radiation, water potential and electrical conductivity, were collected to investigate their influence on the transpiration of African mahogany plants. The research was carried out in an experimental field in the northeast region of Brazil, over a period of four months, with young African mahogany plants (*Khaya senegalensis*), using water with an electrical conductivity of

0.5 dS.m $^{-1}$ (control treatment); 1.25 dS.m $^{-1}$; 2 dS.m $^{-1}$; 2.75 dS.m $^{-1}$; 3.5 dS.m $^{-1}$; 4.25 dS.m $^{-1}$ and 5 dS.m $^{-1}$ in a total of seven treatments, with three replications and 21 experimental units (plants). Plant transpiration was measured using a steady-state diffusion porometer. The electrical conductivity of the irrigation water was monitored using a portable conductivity meter. The results presented in the analyzes indicate a complex and interdependent relationship between leaf transpiration, photosynthetically active radiation and plant water potential. Leaf transpiration is influenced by variations in solar radiation, which plays a crucial role in regulating this process. It was observed that leaf transpiration is lower in the morning, from 7 to 9 am and in the late afternoon, from 5 to 6 pm, when incident solar radiation is at lower values.

Keywords: transpiration, lysimeter, salt stress, water restriction

1. Introduction

Plants face diverse challenges in different environments, and one of the most adverse conditions is the presence of high levels of salinity in the soil (Phogat et al., 2020). African mahogany (*Khaya ivorensis*) is a hardwood species widely cultivated in tropical and subtropical regions (Albuquerque et al., 2013). However, little is known about the behavior and physiological response of young African mahogany plants in saline environments (Santos et al., 2020). In this context, this study seeks to investigate perceptions about transpiration, photosynthetically active radiation and water potential of young African mahogany plants in a saline environment.

Soil salinity occurs when there is an accumulation of dissolved salts in soil water (Al-Muaini et al., 2019). These salts, generally composed of sodium, calcium, magnesium and potassium, can cause an osmotic imbalance in plant roots (HUANG, 2018). This is because the concentration of salts in the soil is greater than the concentration within the root cells (Nabi et al., 2019). As a result, water in root cells is drawn into the soil, resulting in dehydration and water stress (Xiao et al., 2023).

African mahogany is known to be a species resistant to soil salinity compared to other species (França et al., 2016). However, scientific studies have shown that high levels of salinity can affect their growth and development (Van der Sleen et al., 2015); (Ribeiro et al., 2017). The intensity of the effect of salinity on African mahogany can vary according to the age of the plant, stage of development, climatic conditions and concentration of salts in the soil (França et al., 2016).

Photosynthetically active radiation (Qleaf) is a band of the electromagnetic spectrum that provides the energy necessary for photosynthesis (Twohey et al., 2019). In saline environments, the presence of salts in the soil can alter the availability and quality of light, thus affecting the photosynthesis rate of plants (Tian et al., 2020a). Studies have shown that plants grown in saline soils may experience a reduction in Qleaf absorption due to interference caused by salts, resulting in a decrease in photosynthetic rate (Tian et al., 2020b). However, more research is needed to better understand how African mahogany responds to photosynthetically active radiation in saline environments.

Water potential is a measure of water availability for plants and is related to the potential difference between the soil and the atmosphere (Saathoff and Welles, 2021). In saline environments, water potential can be reduced due to water stress caused by the presence of salts (Tian et al., 2020a). Young African mahogany plants exposed to salinity may experience a decrease in water potential, which may negatively affect their growth and development (Albuquerque et al., 2013). Studies have shown that African mahogany has a certain tolerance to salinity (Santos et al., 2020); (Mensah et al., 2023), but further investigation is needed to understand how water potential is affected under these conditions.

Soil salinity occurs when there is an accumulation of dissolved salts in soil water (Gu et al., 2019). These salts, generally composed of sodium, calcium, magnesium and potassium, can cause an osmotic imbalance in plant roots (Kacimov and Obnosov, 2019). This occurs because the concentration of salts in the soil is greater than the concentration within the root cells (Patra et al., 2015). As a result, water in root cells is drawn into the soil, resulting in dehydration and water stress (Li et al., 2020).

African mahogany is known to be a species resistant to soil salinity compared to other species (Casaroli et al., 2018). However, scientific studies have shown that high levels of salinity can affect their growth and development (França et al., 2016). The intensity of the effect of salinity on African mahogany can vary according to the age of the plant, stage of development, climatic conditions and concentration of salts in the soil (França et al., 2016).

Soil salinity affects African mahogany transpiration in several ways. Firstly, the presence of high levels of salts in the soil reduces the availability of water to the roots, due to the osmotic effect (Akhtar, 2019) mentioned above. Water is essential for transpiration as it is transported from the roots to the leaves, where it is released into the atmosphere (Yin et al., 2019). Therefore, the lack of available water limits the transpiration rate of African mahogany.

In addition to direct effects on transpiration, soil salinity can also lead to physiological and biochemical changes (Li et al., 2021) in African mahogany. For example, high levels of salinity can cause oxidative damage in plant cells, resulting in the production of reactive oxygen species (Fan et al., 2020). These reactive oxygen species can damage cell membranes and molecules important for the proper functioning of plants.

Soil salinity affects African mahogany transpiration in several ways. Firstly, the presence of high levels of salts in the soil reduces the availability of water to the roots (Negacz et al., 2022), due to the osmotic effect mentioned above. Water is essential for transpiration as it is transported from the roots to the leaves, where it is released into the atmosphere (Al-Muaini et al., 2019). Therefore, the lack of available water limits the transpiration rate of African mahogany.

The behavior of young African mahogany plants in a saline environment is an important area of research to understand the adaptability of this species to unfavorable conditions. Understanding perceptions about transpiration, photosynthetically active radiation and water potential under these conditions is essential for the appropriate management of African mahogany cultivation in saline soils. The results of this study will provide valuable information about the physiology of young African mahogany plants in saline environments and may contribute to the development of more efficient and sustainable cultivation strategies.

2. Material and Methods

Lysimeters were installed in the experimental field of the State University of Southwest Bahia (UESB), which is located on the Vitória da Conquista campus. The area is characterized by a tropical high-altitude climate (Cwb), according to the Köppen classification (Peel et al., 2007). This indicates that the location has a dry period during the winter and hot, humid summers. The geographic coordinates of the location are approximately 14 degrees 53 minutes 08 seconds south latitude and 40 degrees 48 minutes 02 seconds west longitude in relation to the Greenwich meridian, with an altitude of approximately 881 meters.

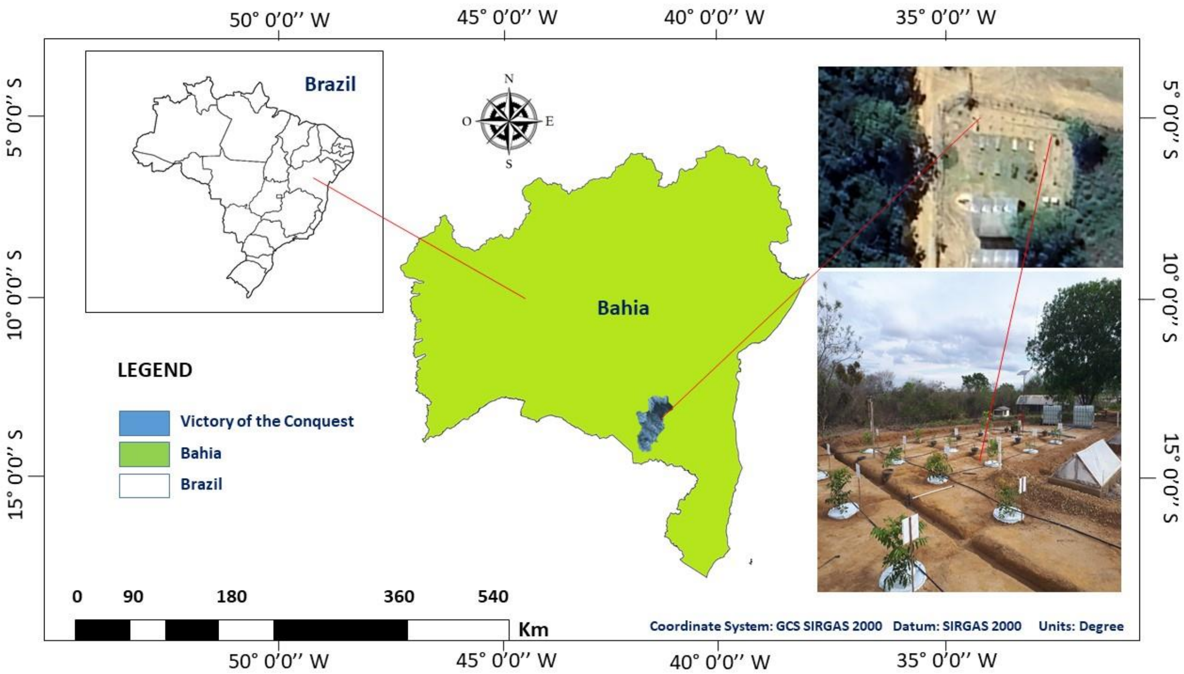

Figure 1. Location of the study area. Area: Vitória da Conquista – BA, northeast of Brazil

The rainy season occurs in the region between the months of November and March, with an annual rainfall of around 700 mm. In relation to average temperatures in the region, maximums of 26.4 °C and minimums of 16.1 °C are recorded, with an annual average of approximately 20.2 °C, according to data provided by INMET (National Institute of Meteorology) referring to 2018.

2.1 Lysimeters

The lysimeters were made of polyethylene (canisters), with cylindrical dimensions, one meter high and a total volume of 0.2 m ^{3}, arranged at ground level in an open field (Figure 2). In the central part of the lysimeter, a 75" PVC tube, 1.6 m long, was inserted, arranged in such a way that water can be stored in the tube and flow to the soil storage region of the lysimeter, through holes located in the tubes (Figure 2.a), storage comprising the portion of the tube that protruded from the outside of the lysimeter , 0.6 m long.

Figure 2. Field experiment. a) Drainage tube with perforation. b) Distribution of drainage lysimeters in the experiment area. c) Pressure camera used to measure water potential. d) Measurement of perspiration with the IRGA analyzer, model LCPro -SD

The lysimeters were filled with an initial layer of gravel in such a way as to completely cover the perforation of the central water drainage tube, which corresponded to a 20 cm layer of gravel, then a 5 cm layer of gravel was added coarse sand. Finally, the soil layer was added, completely filling the interior of the lysimeter, with a depth of 40 cm. After planting the african mahogany seedlings, the lysimeter was covered with a thin layer of cement in order to prevent the evaporation of water from the soil, finally receiving white paint to reduce the soil temperature in the lysimeter.

Leaf transpiration

In this study, we used devices called steady-state diffusion porometers from the LCpro-SD model to analyze the transpiration rate (E) of plants. This equipment allows accurate measurement of transpiration over time, providing valuable information about plant responses to variations in environmental conditions.

The experiment was carried out over the first nine months of the crop's development, with transpiration data collected in the months of January, February and March 2022. We used 21 plants as experimental units, subjecting each one to different levels of electrical conductivity:

0.5 dS.m $^{-1}$; 1.25 dS.m $^{-1}$; 2 dS.m $^{-1}$; 2.75 dS.m $^{-1}$; 3.5 dS.m $^{-1}$; 4.25 dS.m $^{-1}$ and 5 dS.m $^{-1}$, with the control treatment having an electrical conductivity of 0.5 dS.m $^{-1}$. Each treatment was repeated three times.

The distribution of plants in the field was done randomly, ensuring that there was no interference between them. Additionally, each plant was placed individually in a lysimeter, providing controlled measurement conditions. Transpiration was assessed at the leaf level, using leaf transpiration rate as an indicator. We selected three healthy, fully expanded leaves on each plant, located in the middle third of the canopy and exposed to solar radiation throughout the evaluation period.

Perspiration readings were taken at hourly intervals throughout the day, from 7 am to 5 pm, for five consecutive days. During this period, we did not supply water to the lysimeters, which, combined with the different salinity levels applied in each treatment, created conditions of water restriction, resulting in different water potentials in the plants. This procedure was adopted to observe the effect of water restriction on leaf transpiration.

After five days of water restriction, the water supply was established and the experimental units were maintained with the soil at field capacity, returning to the maximum level of 4 liters of water, a volume corresponding to the soil field capacity of the lysimeters. This step allowed the plants to recover after the period of water stress.

By carrying out these measurements and experimental manipulations, our objective is to understand the relationship between plant transpiration and different levels of electrical conductivity, in addition to observing the effects of water restriction on leaf transpiration. The results obtained will be essential to improve water management in crops, seeking a more efficient use of this resource and maximizing agricultural productivity in different conditions.

Leaf water potential (Ψw)

During the experimental phase of the study, plants were selected as samples, and three leaves from each plant were collected in the middle region of the shoot. These leaves were collected before dawn, in the early morning period, at 5 am which time is considered dawn and early morning. To determine this potential, we adopted the method described by (Scholander et al., 1965), which involves the use of a pressure chamber as an auxiliary tool. This approach allows us to quantify the water storage capacity of leaves, providing valuable information about the hydration level of plants and their performance in relation to the environment.

Climate factors

In order to establish a relationship with the evapotranspiration rate (E), we decided to use photosynthetically active radiation as one of the variables of interest. This radiation (Qleaf) was measured simultaneously with E, using a sensor connected to the porometer chamber. The sensor was positioned perpendicular to the sunlight incident on the leaf surface throughout each working day, allowing an accurate assessment of the amount of radiation available for photosynthesis.

Additionally, to obtain complementary and more detailed information about environmental conditions, we collect air temperature and relative humidity data daily. These data were recorded at the meteorological station of the National Institute for Space Research (INPE), located in the experimental area of the State University of Southwest Bahia (UESB), at a distance of 300 meters from the lysimeters where the measurements were carried out. By combining these environmental variables with the evapotranspiration rate, we seek to perform a comprehensive analysis of the factors that influence plant water balance and their physiological performance.

Method of analyzing results

With the help of SISVAR 5.6 software, regression models were developed to better explain leaf transpiration (E) as a function of photosynthetically active radiation (Wleaf) by class of Ψpd for different levels of electrical conductivity. With the response curve of the models, it was possible to define the light saturation point for the situation.

Analysis of variance and regression analysis

The results were subjected to analysis of variance (ANOVA), using the F test (Table 1) to compare means, and regression analysis for the quantitative study of the characteristics evaluated, using the statistical program SISVAR 5.6 and STATISTICA with subsequent analysis of regression in the study between each treatment without including the control, and the control treatment will be compared with the others using the Dunnet test ($p < 0.05$).

Table 1. Description of the components of the analysis of variance framework used to compare treatment averages (electrical conductivities)

Source of Variation	Degrees of freedom	Sum of Squares	Squares Midfielders	F calculated
Treatments	I-1	SQTrat	QMTrat	QMTrat / QMRes
Residue	I(J-1)	SQRes	QMRes	
Total	IJ-1	SQTotal		

On what:

$$SQTotal = \sum_{i=1}^{I} \sum_{j=1}^{J} y_{ij}^2 - C, \text{ where } C = \frac{\sum_{i=1}^{I} \sum_{j=1}^{J} y_{ij}^{\ 2}}{IJ} \quad (1)$$

Measures the overall variation of all observations.

$$SQTrat = \frac{\sum_{i=1}^{I} y_i^2}{J} - C \quad (2)$$

Sum of squares of groups (treatments), associated exclusively with an effect of groups (between electrical conductivities).

The sum of squares of the residuals was obtained by difference:

$$SQRes = SQTotal - SQTrat \quad (3)$$

Sum of squares of residuals, due exclusively to random error, measured within groups (repetitions of each treatment).

$$QMtrat = \frac{SQtrat}{I-1} \quad (4)$$

Being the square mean of the groups (treatments).

$$QMRes = \frac{SQRes}{I(J-1)} \quad (5)$$

Being the square mean of the residues (between repetitions of each treatment).

To verify a significant difference between treatments, represented by the different electrical conductivities of irrigation water (effect of groups, between treatments, and within groups, repetitions of each treatment), the F test was used, considering that, if calculated F > tabulated F, the F test is rejected null hypothesis H_0, that is, there is evidence of a significant difference between at least one pair of treatment means, at the chosen level α of significance, with a 5% probability in the case under study. Otherwise, the null hypothesis H_0 can not be rejected, that is, there is no evidence of a significant difference between electrical conductivities (treatments), at the chosen level α of significance.

To generate the regression equations, the least squares method was used, trying to minimize the sum of the squares of the differences between the estimated value (regression equation) and the observed transpiration data of the mahogany crop, such differences being called residuals, and expressed mathematically by:

$$\sum_{i-1}^{n} e_i^2 \quad (6)$$

On what:

n = represents the number of observations, being the number of sampled temperature and precipitation data;

e = difference between the real value of temperature and precipitation data observed during the period of time and those estimated by the equation.

To measure the quality of the model in relation to its ability to correctly estimate the values of the crop transpiration response variable (E) (dependent variable) as a function of environmental variables (global radiation (Rg), photosynthetically active radiation (Qleaf), and water potential - independent variable) the correlation coefficient R^2, determined by:

$$R^2 = 1 - (QRes / SQTot) \quad (7)$$

Where: SQRes = sum of squares of the residue;

SQTot = total sum of squares.

The value of R^2, can take values from 0 to 1, and the higher the value of the correlation coefficient, the closer to the real data are the data estimated by the regression equation model generated, being obtained for the analysis of the dependent variable, crop transpiration, as a function of environmental variables (independent variable), correlation coefficient values greater than 70%.

4. Results

Figure 3 shows transpiration in plants with different water potentials over time, from 6:00 am to 6:00 pm, during five consecutive days of water restriction (March 14, 15, 16, 17 and 18, 2022).

In the figure, it can be seen that the total daily transpiration on the days evaluated presents lower values in the first hours of the day and at the end of the daily period, around 6 pm. This occurs when incident solar radiation is at lower values. This observation is valid for all water potentials studied.

Throughout the day, perspiration varies between different water potentials in the same assessment period. However, the oscillatory behavior of transpiration is similar for all water potentials. For the periods evaluated (14, 15, 16, 17 and 18 March), the average value of leaf transpiration is approximately 15 $mmol.m^{-2}.s^{-1}$.

However, there is a representative variation between different water potentials for the same assessment day. In this case, leaf transpiration decreases as the water potential value decreases.

Figure 4 shows the variation in photosynthetically active radiation in plants with different water potentials over time, during five consecutive days of water restriction.

Photosynthetically active radiation exhibits an oscillatory pattern throughout the day, similar to a parabola, with lowest values in the first and last hours of the day and a maximum peak around noon, around 12 noon.

Furthermore, it is possible to notice that radiation values fluctuate throughout the day, with variations between maximum and minimum values in a short period of time.

These variations can be attributed to local meteorological conditions, such as the presence of clouds, which can block part of the solar radiation.

When comparing Figure 4 with Figure 3, which represents leaf transpiration, you noticed that they present the same oscillatory variation throughout the analyzed period. This indicates that leaf transpiration is being influenced by variations in photosynthetically active solar radiation.

In this context, photosynthetically active solar radiation acts as an independent variable that conditions leaf transpiration values, which in turn is a variable dependent on solar radiation.

Photosynthetically active radiation and leaf transpiration is expected, as leaf transpiration is a process regulated by the plant to control water loss.

The amount of available solar radiation affects the rate of photosynthesis and, consequently, the opening of leaf stomata, which are involved in transpiration. Thus, variations in solar radiation can directly influence plant leaf transpiration.

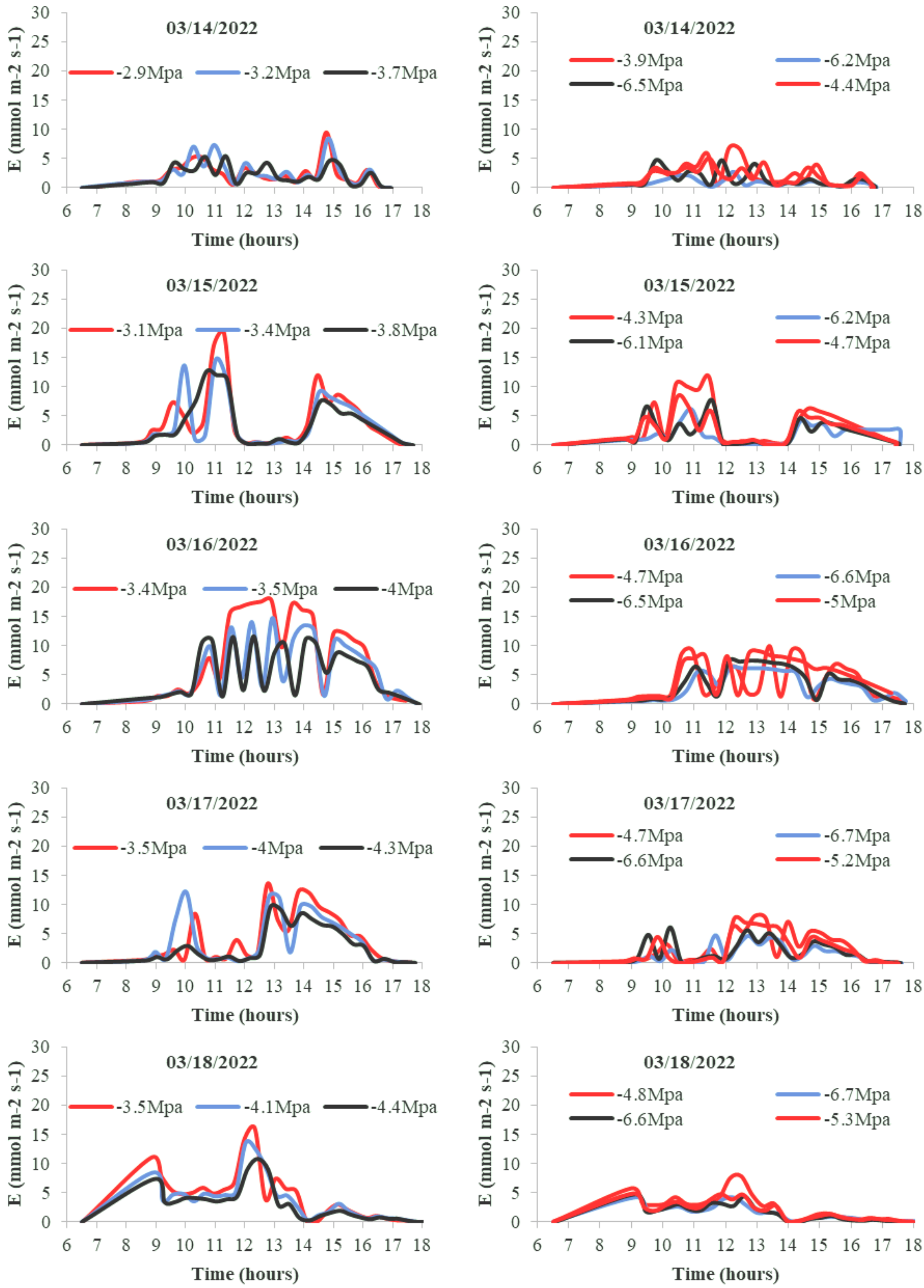

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Figure 3. Perspiration in plants with different water potentials, depending on time, from 6:00 am to 6:00 pm, for the period 14; 15; 16; March 17 and 18, 2022, totaling five consecutive days of water restriction

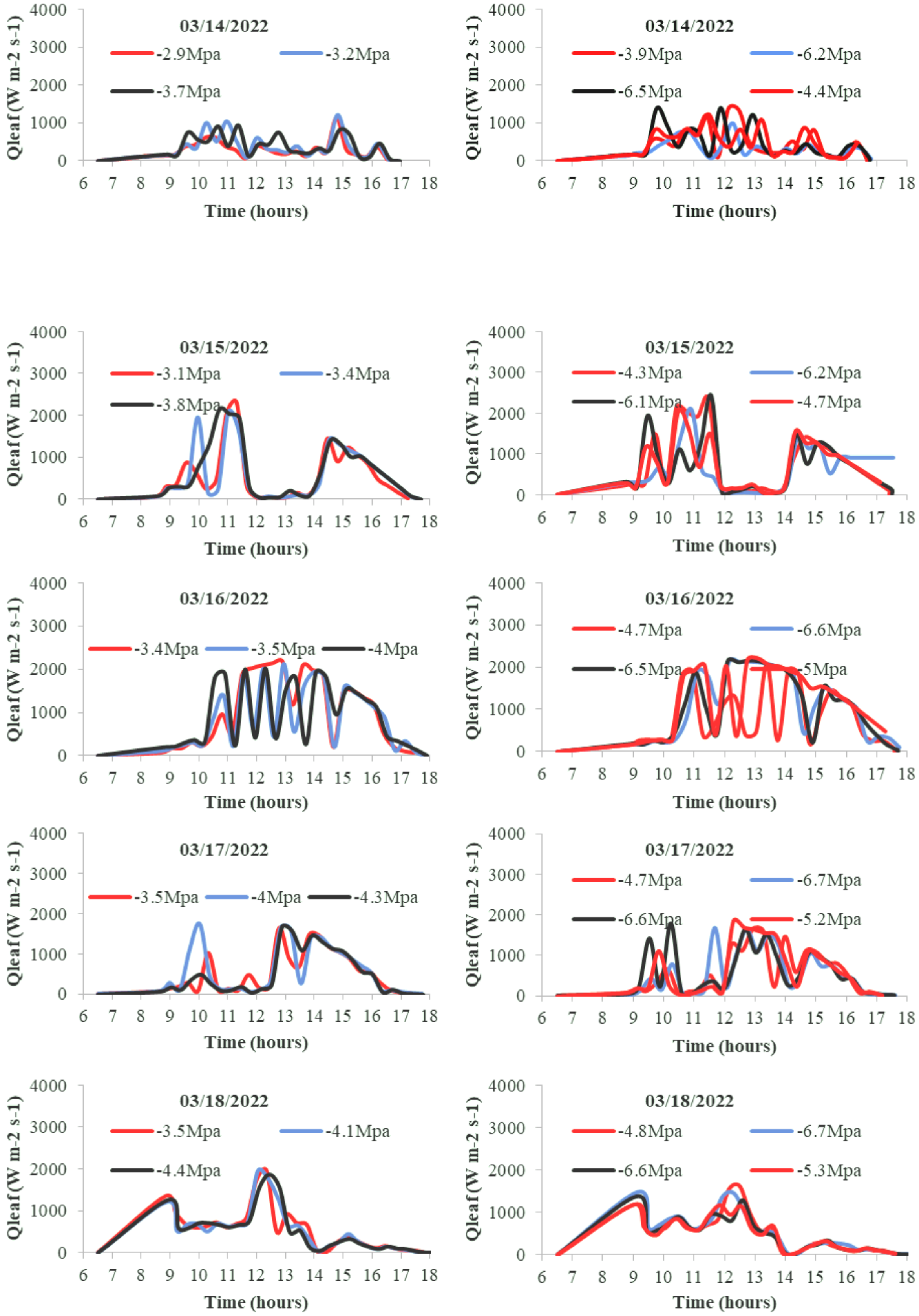

Figure 4. Photosynthetically active radiation in plants with different water potentials, as a function of time, in the period from 6:00 am to 6:00 pm, for the period 14; 15; 16; March 17 and 18, 2022, totaling five consecutive days of water restriction

It is possible to observe in Figure 5 the ratio between transpiration and photosynthetically active radiation, that is, the amount of energy used for the mahogany plant to transpire in salinity conditions with different water potentials, this relationship between leaf transpiration and Qleaf presents peaks at the beginning and end of the day for all time periods studied, this is due to the influence of the vapor pressure deficit (DPV) acting on the leaf transpiration/ photosynthetically active radiation relationship. Based on the analysis of Figure 8, it can be observed that the ratio between transpiration and photosynthetically active radiation decreases as the water potential increases in module. In other words, when water potentials become more negative, the plant requires a greater amount of photosynthetically active radiation to transpire. This analysis is valid for the entire study period.

Photosynthetically active radiation, in relation to the variation in water potential, generated the mathematical model **$y = 0.0136e^{(-0.265x)}$**, where y represents the transpiration/ photosynthetically active radiation ratio and x represents the water potential. The correlation coefficient (R^2) of this model is 0.4243. This means that approximately 42.43% of the variability in the transpiration/ photosynthetically active radiation ratio can be explained by the variation in water potential according to this model.

The daily average of transpiration and stomatal conductance is illustrated in Figure 8 for each day of the water restriction period, with the consecutive averages of water potentials of the three replicates of mahogany plants, for each day. As the water potential decreases as the days go by, the daily average of transpiration decreases, presenting its highest value on the first day with an average water potential of -2.47 Mpa. The same behavior is observed in the variation in stomatal conductance over the period of time analyzed, January 28th, 29th, 30th and 31st, with the respective average decrease in stomatal conductance.

Figures 6 and 7 show the relationship between leaf transpiration and stomatal conductance as a function of photosynthetically active radiation for different evaluation periods during the study. Each figure corresponds to a specific period, indicated by dates. In Figures 6 and 7, one can observe the dispersion of leaf transpiration and stomatal conductance values in relation to photosynthetically active radiation for different treatments, represented by different electrical conductivities. This dispersion is observed for all days of the week in the respective evaluation periods.

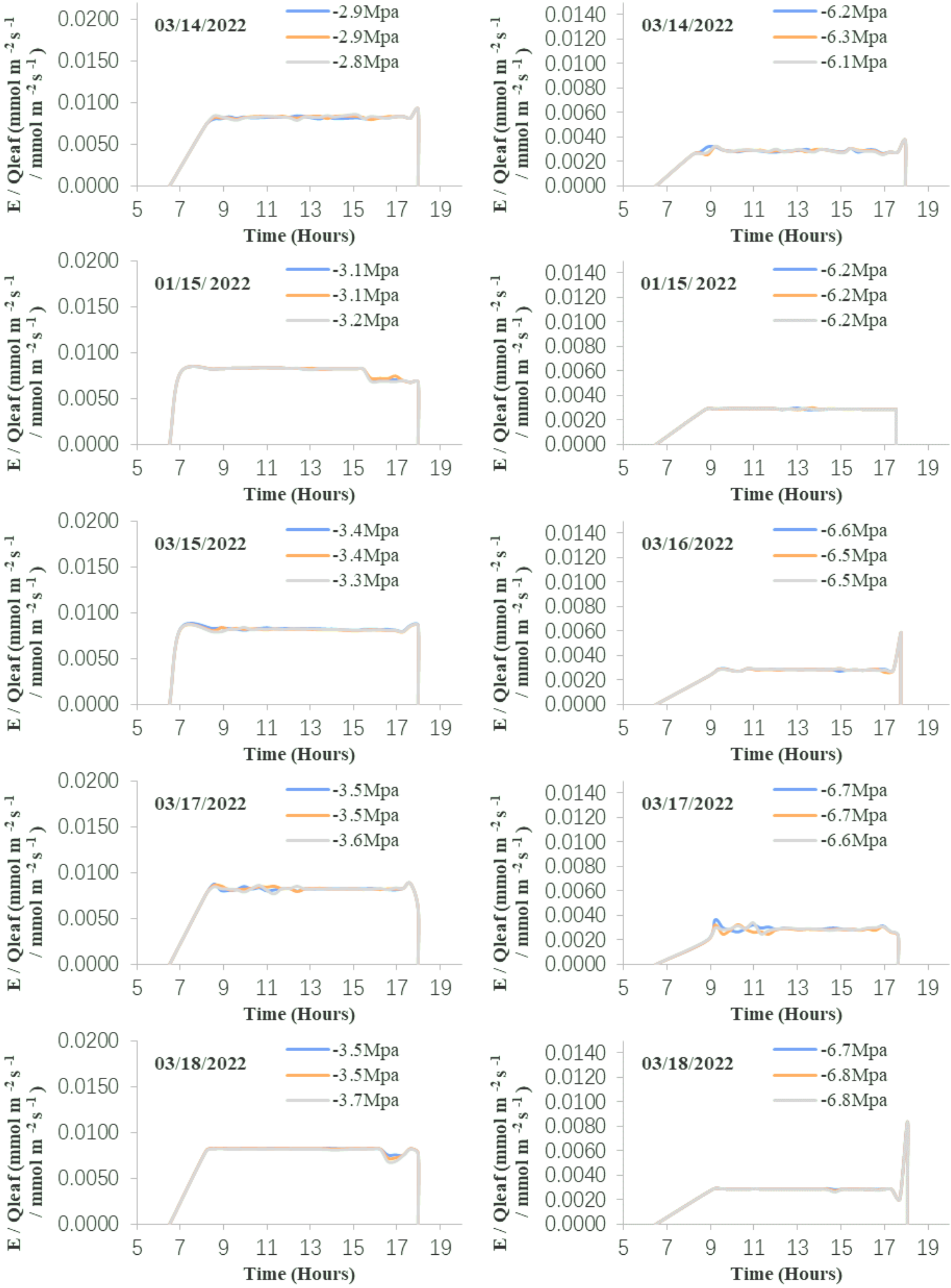

Figure 5. Relationship between transpiration and photosynthetically active radiation (Qleaf) in plants with different water potentials, as a function of time, for electrical conductivity of 05 dS.m $^{-1}$ and 5 dS.m $^{-1}$, in the period from 6:00 am to 6:00 pm, for the period of 14; 15;16; January 17th and 18th, 2022, totaling five consecutive days of water restriction

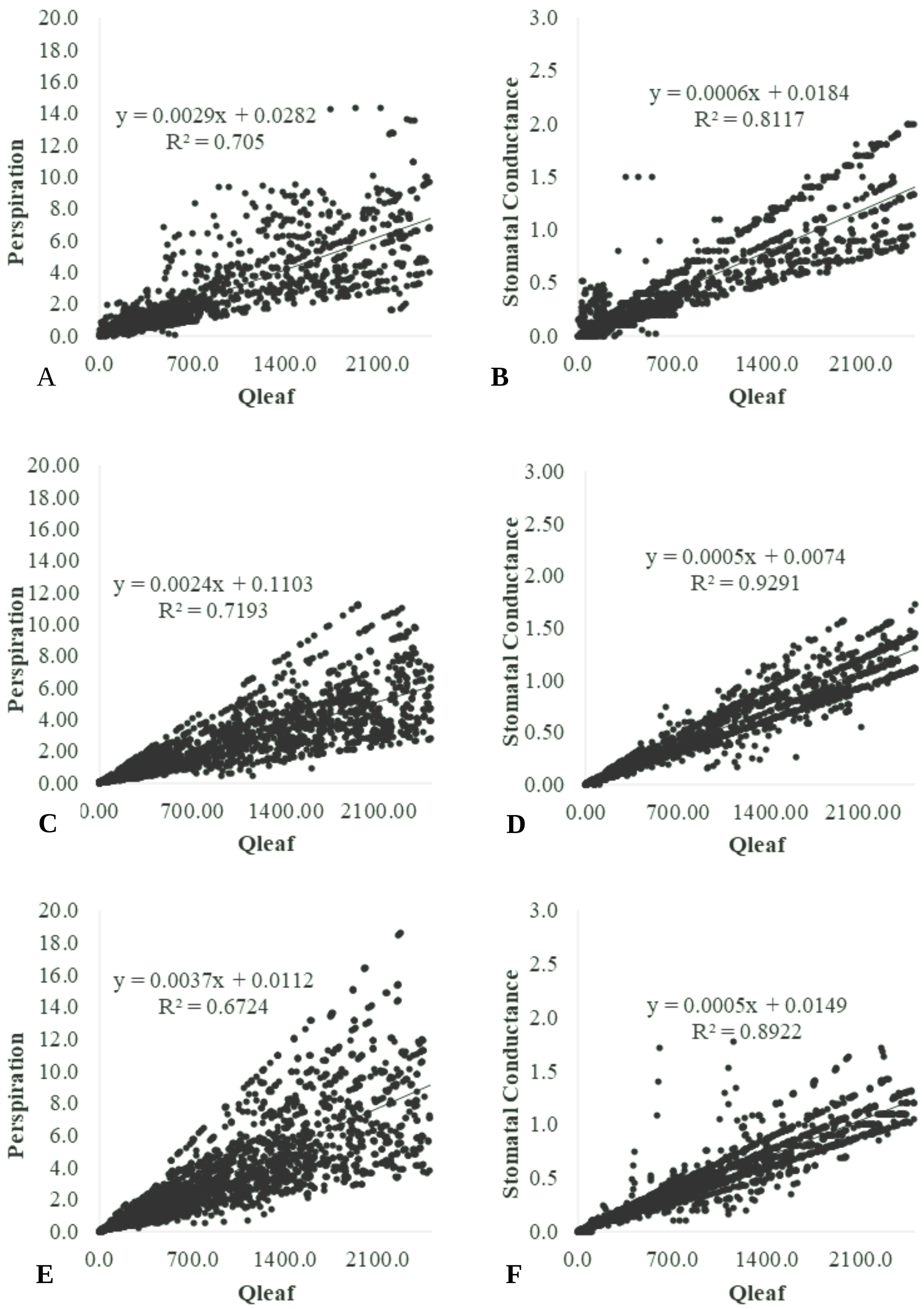

Figure 6. **A**, **C, E**: Leaf transpiration as a function of photosynthetically active radiation for the period 28 – 31/01/2022 (A), 7 – 11/02/2022 (C) and 19 – 23/02/ 2022, with their respective correlation functions. **B, D, F**: Stomatal Conductance as a function of photosynthetically active radiation for the period 28 – 31/01/2022 (A), 7 – 11/02/2022 (C) and 19 – 23/02/2022 (E), with their respective correlation functions

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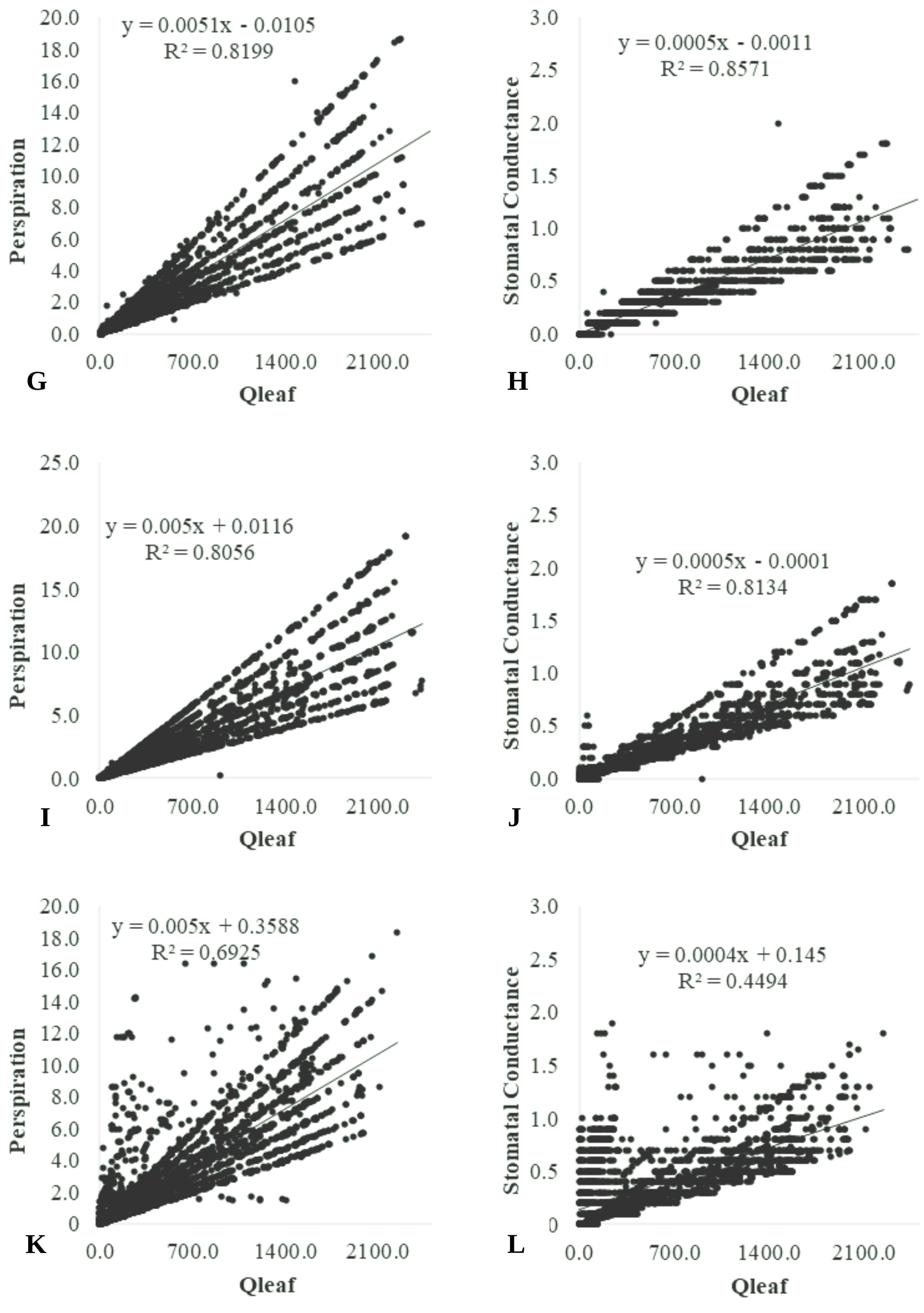

Figure 7. **G**, **I, K**: Leaf transpiration as a function of photosynthetically active radiation for the period 28/2 – 04/03/2022 (G), 14 – 18/03/2022 (I) and 24 – 29/03 /2022 (K), with their respective correlation functions. **H, J, L**: Stomatal Conductance as a function of photosynthetically active radiation for the period 28/2 – 04/03/2022 (H), 14 – 19/03/2022 (J) and 24 – 29/03/2022 (L), with their respective correlation functions

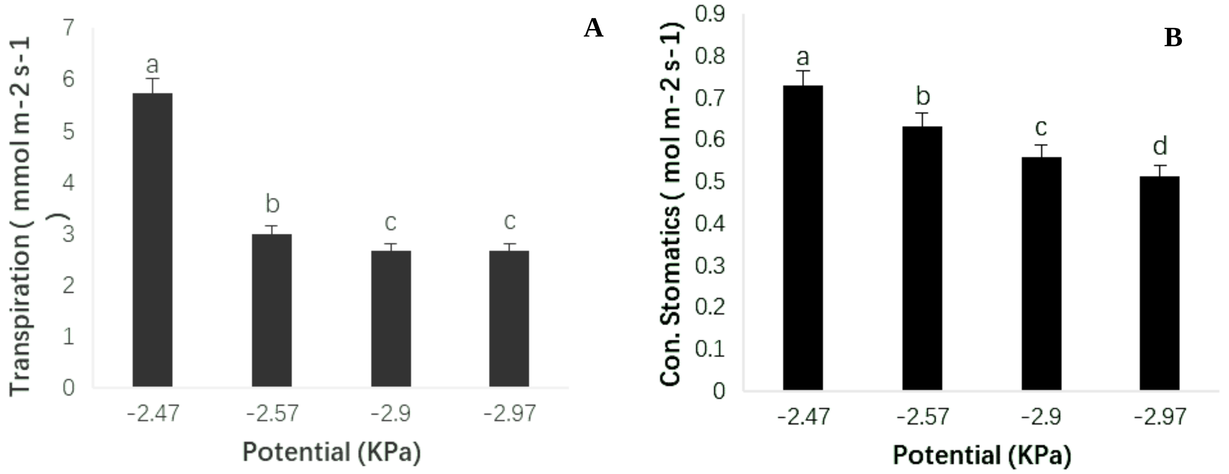

Figure 8. Average daily transpiration (A) and Stomatal Conductance (B) in the total period of water restriction (January 28, 29, 30 and 31) with consecutive water potentials for each period of day. Means followed by the same letter do not differ according to the Tukey test at 5% probability

For relationships between variables, it is possible to generate mathematical linear correlation models, each with their respective correlation coefficients. These models allow estimating or predicting leaf transpiration and stomatal conductance values based on photosynthetically active radiation. Figures 6 and 7 present the specific details of the linear correlation mathematical models and the correlation coefficients associated with each evaluation period.

5. Discussion

Analysis of Figure 3 reveals important information about transpiration in plants with different water potentials over time. During the five consecutive days of water restriction (March 14, 15, 16, 17 and 18, 2022), total daily transpiration presents lower values in the first hours of the day (from 6 am to 9 am) and at the end of the daily period, around 6 pm. These periods correspond to times when incident solar radiation is at lower values. This observation is valid for all water potentials studied, indicating that transpiration is influenced by the amount of available solar radiation.

Throughout the day, perspiration varies between different water potentials in the same assessment period. However, the oscillatory behavior of transpiration is similar for all water potentials. This suggests that the variation in leaf transpiration occurs in a similar way, regardless of the water potential of the plants. However, it is important to note that there is a representative variation between different water potentials for the same assessment day. In this case, leaf transpiration decreases as the water potential value decreases. This indicates that water availability directly affects the transpiration rate of plants.

Figure 4, in turn, shows the variation in photosynthetically active radiation in plants with different water potentials over time, during the same five consecutive days of water restriction. Photosynthetically active radiation exhibits an oscillatory pattern throughout the day, resembling a parabola. Radiation values are lower in the first and last hours of the day, reaching a maximum peak around midday, around 12 noon. This daily variation in photosynthetically active radiation is related to the diurnal cycle of available sunlight.

Furthermore, Figure 4 shows that the values of photosynthetically active radiation fluctuate throughout the day, with variations between maximum and minimum values in a short period of time. These oscillations can be attributed to local meteorological conditions, such as the presence of clouds, which can block part of the incoming solar radiation. These variations in solar radiation can directly affect the rate of photosynthesis and, consequently, the leaf transpiration of plants.

When comparing Figure 4 with Figure 3, it is possible to observe that they present the same oscillatory variation throughout the analyzed period. This suggests that leaf transpiration is being influenced by variations in photosynthetically active solar radiation. Solar radiation acts as an independent variable that conditions leaf transpiration values, which, in turn, is a variable dependent on solar radiation. This relationship is expected, as leaf transpiration is a process regulated by the plant to control water loss, and the amount of available solar radiation affects the rate of photosynthesis and the opening of stomata in leaves, thus influencing transpiration.

Photosynthetically active radiation may be associated with factors beyond water restriction, such as latitude, season, cloud cover and other climatic factors. Therefore, it is essential to consider these variables when interpreting the relationship between photosynthetically active radiation and leaf transpiration.

Photosynthetically active radiation (Qleaf) in plants with different water potentials and subject to salinity conditions, as evidenced in Figure 5, reveals important information about how plants respond to these environmental stresses.

When analyzing Figure 5, it can be seen that the relationship between transpiration and photosynthetically active radiation presents peaks in the early hours of the day and late afternoon for all time periods studied. These peaks can be attributed to the influence of vapor pressure deficit (DPV) on the leaf transpiration/ photosynthetically active radiation relationship. DPV is a measure of the amount of water vapor in the air and is related to the air's ability to absorb more water. In the early hours of the day and late afternoon, the DPV is lower, which results in a greater amount of water vapor present in the atmospheric air.

In salinity conditions and with different water potentials, the plant requires a greater amount of energy from photosynthetically active radiation to carry out leaf transpiration. This is because transpiration is a process that involves the loss of water by plants, and the amount of water that can be lost depends on the availability of water vapor in the environment. Therefore, in the early hours of the day and late afternoon, when the DPV is lower and the amount of water vapor is greater, the plant needs a greater amount of photosynthetically active radiation to sustain leaf transpiration, resulting in the peaks observed in leaf transpiration/ photosynthetically active radiation ratio.

These results are consistent with previous studies that investigated the influence of water stress and salinity on leaf transpiration and plant water balance (Goto et al., 2021; Bhusal et al., 2019; Durand et al., 2020). The relationship between transpiration and photosynthetically active radiation is an important measure to understand how plants respond to these stresses and how they optimize the use of available solar radiation to perform transpiration, even in unfavorable conditions.

Understanding these patterns of plant response to the leaf transpiration/ photosynthetically active radiation relationship under conditions of water stress and salinity is essential for the adequate management of crops in regions affected by these environmental factors. The use of appropriate irrigation techniques and the development of plant varieties that are more tolerant to salinity are strategies that can be adopted to minimize the negative effects of these stresses on plants and maximize the efficiency of the use of solar radiation.

Based on the analysis of Figure 4, it is observed that the ratio between transpiration and photosynthetically active radiation decreases as the water potential increases in module. In other words, the more negative the water potential, the greater the amount of photosynthetically active radiation needed for the plant to transpire. This result suggests that water availability affects the plant's response to solar radiation, thus influencing transpiration.

To avoid water loss, with the decrease in water potential, plants reduce the transpiration mechanism and stomatal conductance (Figure 8), this process being more evident in Gs, occurring due to less water availability (Carrière et al., 2020) , due to the water restriction, which the plants were subjected to throughout the days of the experiment.

Figures 6 and 7 complement the analysis, providing information on the relationship between leaf transpiration, stomatal conductance and photosynthetically active radiation for different evaluation periods during the study. These figures show the dispersion of leaf transpiration and stomatal conductance values in relation to photosynthetically active radiation for different treatments and evaluation periods. It is possible to observe that both leaf transpiration and stomatal conductance increase with the increase in photosynthetically active radiation. This direct relationship indicates that these variables are influenced by the variation in incident solar radiation.

Based on these observations, it can be concluded that photosynthetically active radiation plays a crucial role in regulating leaf transpiration in plants. The availability of solar radiation affects the rate of photosynthesis and, consequently, the opening of stomata, controlling water loss through transpiration. Furthermore, the relationship between photosynthetically active radiation and leaf transpiration is mediated by the water potential of plants. Water potential influences plants' response to solar radiation, modulating the rate of transpiration.

Photosynthetically active radiation and the water potential of plants has been the subject of study in several scientific studies. Several academic works have investigated this interaction and sought to understand the mechanisms involved in this relationship.

A study carried out by Xie et al. (2018) examined the relationship between leaf transpiration and photosynthetically active radiation in different plant species under water stress conditions.

The results showed that leaf transpiration decreased as photosynthetically active radiation decreased, indicating a strong dependence of transpiration on solar radiation. Furthermore, the study revealed that the rate of transpiration varied between different species, suggesting that the response to solar radiation may be specific to each plant.

Another study conducted by Li et al. (2019) investigated the relationship between leaf transpiration and water potential in rice plants under different irrigation conditions. The results showed that leaf transpiration decreased as water potential decreased, corroborating the findings of the present analysis. Furthermore, the study revealed that the transpiration rate was strongly influenced by water potential, highlighting the importance of water availability in regulating transpiration.

With regard to the mathematical models used to describe the relationship between leaf transpiration, photosynthetically active radiation and water potential, several studies have proposed different approaches. A study carried out by Zhang et al. (2020) developed a nonlinear model to describe the relationship between transpiration and photosynthetically active radiation in wheat plants. The model incorporated not only solar radiation, but also other variables such as temperature, air humidity and CO_2 concentration. The results showed a good agreement between the observed and simulated values, highlighting the model's ability to describe the complex relationship between these variables.

Another relevant study was conducted by Wang et al. (2017), who investigated the relationship between stomatal conductance, transpiration and photosynthetically active radiation in maize plants under different water stress conditions. The study proposed a linear correlation mathematical model to describe the relationship between these variables. The results indicated that stomatal conductance and transpiration were positively correlated with photosynthetically active radiation, corroborating the findings of the present analysis.

Photosynthetically active radiation and plant water potential. They provide additional scientific support to the results found in the present analysis, strengthening the understanding of these phenomena and providing valuable insights for practical applications such as irrigation management and optimization of agricultural productivity.

The available scientific evidence corroborates the results and conclusions presented in this analysis. The relationship between leaf transpiration, photosynthetically active radiation, and water potential is an area of active research, with several studies investigating this interaction. The mathematical models proposed in different studies have contributed to the understanding and prediction of these complex relationships. However, it is important to highlight that research in this area is still ongoing, and there is room for additional investigations aimed at a more comprehensive understanding of these phenomena and their practical applications.

6. Conclusions

- The results presented in the analyzes indicate a complex and interdependent relationship between leaf transpiration, photosynthetically active radiation and plant water potential. Leaf transpiration is influenced by variations in solar radiation, which plays a crucial role in regulating this process. It was observed that leaf transpiration is lower in the first hours of the day (from 6 am to 9 am) and at the end of the daily period (from 5 pm to 6 pm), when incident solar radiation is at lower values.

- Photosynthetically active radiation exhibits an oscillatory pattern throughout the day, with lowest values in the first (from 6 am to 9 am) and last hours (from 5 pm to 6 pm) and a maximum peak around noon. This variation is related to meteorological factors, such as the presence of clouds, which can affect the amount of solar radiation that reaches the plants.

- It was observed that the ratio between transpiration and photosynthetically active radiation decreases as water potential increases in module. This indicates that, under conditions of greater water stress, plants require a greater amount of solar radiation to carry out transpiration.

- The mathematical models proposed in this study made it possible to describe and quantify the relationships between the variables studied. The correlation coefficients obtained indicate the proportion of variability in leaf transpiration and stomatal conductance that can be explained by variation in photosynthetically active radiation.

- Photosynthetically active radiation in plants subject to salinity conditions and different water potentials shows peaks in the early hours of the day (from 6 am to 9 am) and late afternoon (from 5 pm to 6 pm). These peaks are attributed to the influence of vapor pressure deficit on this relationship, resulting in a greater energy demand from photosynthetically active radiation to sustain leaf transpiration.

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Authors contributions

The Prof. Doctor José Teixeira and Prof. Doctor Alcebíades Rebouças were responsible for designing and reviewing the study. Doctor Willian Campos was responsible for data collection. Doctor Willian Campos wrote the manuscript and Prof. Doctor José Teixeira reviewed it. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

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The Publication Ethics Committee of the Macrothink Institute.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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