Monitoring canopy and air temperature of dominant vegetation in tropical semi-arid using bioclimatic model

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A R T I C L E I N F O	A B S T R A C T
	Typical vegetation of arid environments consists of few dominant species highly threatened by climate change. Jurema preta (*Mimosa tenuiflora* (Willd.) Poiret) is one of these successful species that now is dominant in huge semi-arid areas in the world. The development of a simple bioclimatic model using climate change scenarios based on optimistic and pessimistic predictions of the Intergovernmental Panel on Climate Change (IPCC) shown as a simple tool to predict possible responses of dominant species under dry land conditions and low functional biodiversity. The simple bioclimatic model proved satisfactory in creating climate change scenarios and impacts on the canopy temperature of Jurema preta in semi-arid Brazil. The bioclimatic model was efficient to obtain spatially relevant estimations of air temperature from determinations of the surface temperature using satellite images. The model determined that the average difference of 5°C between the air temperature and the leaf temperature for Jurema preta, and an increase of 3°C in air temperature, promote an increase of 2°C in leaf temperature. It leads to disturbances in important physiological mechanisms in the leaf, mainly the photosynthesis and efficient use of water. **Keywords:** climate change, model, leaf temperature, Caatinga, *Mimosa tenuiflora*.

Introduction

Aridity is the major environmental condition that influences the surveillance of plants, especially in consequence of water scarcity. Some successful species became dominant in the major arid regions of the world. Driest regions in the world are characterized by species capable of surviving and completing its life cycle under a scarcity of water, like in Asia, Americas, United States, Chile and Argentina (Burkart, 1976). It is particularly true in tropical regions with the lowest rainfall during the year, like in Africa and South America. Perennial plants contribute to influence the climate, especially the air temperature, improving the predictability of the climate conditions through the temperature alleviation.

Climate models indicate increased irregularities and decreased rainfall in semi-arid regions in the world (Marengo, 2007). If these future scenarios occur, some plant species may disappear. Many researchers have been interested in developing studies on ways to minimize the impact of climate changes on natural resources (Marengo, 2007; Da Silva et al., 2009; Santos et al., 2009; Galvíncio et al., 2010; Galvincio & Moura, 2010).

The leaf temperature is one fundamental feature to understanding many performances in functional plant ecology. Its significance in plants' water relations was recognized early in the 20th century (Raschke, 1960). Based on research on the heat transfer between plants and the environment and on plants' water management, the canopy temperature has been used as an indicator in agri-horticulture since the 1960s (Fuchs & Tanner, 1966; Jackson et al., 1977; Fuchs, 1990; Jones,

2004). Other applications, such as climate modeling of the earth's surface (Dai et al., 2004), assess how increases in the surface temperatures could be caused by global warming (Zaitchik et al., 2006).

The use of aircraft and satellites can determine the temperature and the deforestation from vast areas of land in a short time. The current models need adjustment to the new technologies, especially to explain the environmental variations in the canopy and among the species. As opposed to the average temperature obtained by satellites, the distribution of temperature (using a scale and diurnal variations) is determinant to the flow of heat and gasses between surface and atmosphere. In temperate and tropical forests, in particular for trees with large leaves, the canopy temperatures can substantially differ among species (Grace, 1977).

The energy equilibrium in a leaf of a dominant species established in hard adverse climatic conditions, especially high temperatures, informs about the grade of the influence of this vegetation coverture in extensive areas. Due to evapotranspiration, the temperature in the leaves may be a few degrees below the air temperature (Pillar, 1995); it regulates the transpiration and photosynthesis of the leaf (Larcher, 2003). Stomatal conductance is a powerful physiological mechanism that allows plants to control vascular perspiration. Stomatal resistance is a response to several environmental factors that affect its behavior simultaneously. In illuminated leaves, it depends on the air temperature, the vapor pressure deficit, the concentration of CO_2 and the water potential in the soil (Pimentel & Perez, 2000). These authors also point out that an increase of solar radiation, and consequent higher air temperature, causes increased stomatal resistance by reducing the potential for soil water. Several studies claim that light and water are the two environmental factors with the greatest effects on the behavior of stomata (Silva et al., 1998), and influence the leaf temperature. As a consequence, this study aimed to develop a bioclimatic model to monitoring the canopy surface temperature and air temperature in areas covered with dominant semi-arid vegetation in tropics.

Material and Methods

The study considered extensive areas covered by savanna vegetation, popularly named caatinga in Brazil, with a predominance of individuals of *Mimosa tenuiflora* (Willd.) Poiret, a shrub species, in the municipally of São José do Sabugi, at Paraíba State, Brazil (Figure 1). This area comprises 215.4 km^2 with an average annual precipitation of 500 mm (Galvíncio et al., 2010), concentrated from January to April and temperatures around 28ºC (Moura et al., 2012), always lower than 40ºC (Prado, 2003).
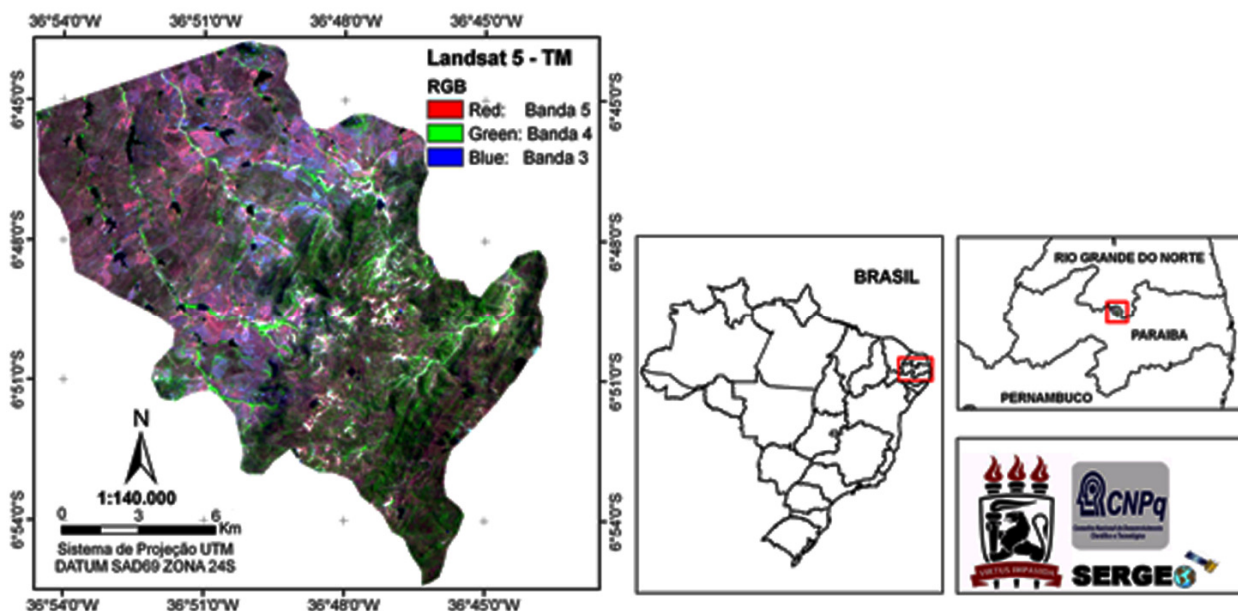

Figure 1. Spatial localization of the municipally of São José do Sabugi, in Paraíba, Brazil.

On January 13, 2009, five variables: leaf surface temperature of Jurema preta, air humidity, air temperature, soil surface temperature and soil temperature at 10 cm depth were obtained at five coordinates: a) site 01 - 738 574 x, 9246370 y; b) site 02 - 738 549 x, 9246394 y; c) site 03 - 736 409 x, 9245108 y; d) site 04 - 742 458 x, 9243340 y; e) site 05 - 741 448 x, 9240072 y, with six sampling

per coordinate. All measurements in the field were made on a clear sky day.

The temperature and humidity were measured with a portable digital thermo-hygrometer (Model THGR122NX, Oregon Scientific, USA) (Figure 3). The surface temperatures of the soil and leaves were measured with a digital infrared thermometer laser (Model 7662, Incoterm, China). The soil temperature was measured with a thermometer from Incoterm.

Temperature measurements of the ground surface were obtained with sensors located at a distance of 1 m from the surface with a zenith angle of 90º. The temperatures of air and leaf surface were measured with sensors at 1.5 m height and angle of 180º. A digital camera with the RICOH 500SE GPS was used with infrared sensors for collecting georeferenced images of plants and canopy. Measures from the surface temperature of canopy and air were correlated.

Figure 2. Vegetation coverage with Jurema preta (*Mimosa tenuiflora* (Willd) Poiret) in São José do Sabugi-PB, in the semi-arid northeastern of Brazil. Sampling sites at five coordinates: a) site 01 - 738 574 x, y 9246370; b) site 02 - 738 549 x, y 9246394; c) site 03 - 736 409 x, y 9245108; d) site 04 - x 742 458, y 9243340; e) site 05 - x 741 448, y 9240072.

Data from the meteorological station came from the Oregon weather station WMR-9x8, in the Datalogger WMR918/928/968, using the software WMRDL Monitor and sent to Excel. This study used data of the air temperature from January 13, 2009. The sensors to detect the temperature and humidity of the weather stations were installed at 1.5 m height. Measures from the meteorological station were correlated with field data of five replicates during one day in the times of 7.5, 8.0, 11.5, 15.5 and 16 hours, on January 13, 2009.

An image from Landsat 5 - TM on January 13, 2009, from orbit 215 and point 65, was used to estimate the surface temperature of the canopy and

after to establish a correlation with similar data collected in the field.

The image processing used the equations published previously by many authors (Markham & Baker, 1987; Huete, 1988; Huete & Warrick, 1990; Bastiaanssen, 1995; Bastiaanssen, 2000; Accioly et al., 2002; Allen et al., 2002; Boegh et al., 2002; Silva et al., 2005; Galvíncio et al., 2010), including the measurements of the estimation of the temperature surface.

The emissivity obtained in the previous step was used to determine the surface temperature (Ts) applied in the spectral radiance of the thermal band

for $L_{\lambda,6}$ and ε_{NB}. Thus, the surface temperature (K) data were obtained from the following expression:

$$T_s = k_2 / 1n \cdot (\varepsilon_{NB}.K_1 / L_{\lambda,6} + 1),$$

where $K_1 = 607.76\ Wm^{-2}sr^{-1}\mu m^{-1}$ and $K_2 = 1260.56$ K were the calibration constants for the thermal band of Landsat 5 - TM (Allen et al., 2002; Silva et al., 2005; Galvíncio et al., 2010).

Descriptive statistics and Pearson correlation analysis were applied to the variable's air temperature, air humidity, soil and leaf surface temperature and soil temperature at 10 cm depth.

The mathematical formulation of the model was a result of the statistical method of multiple linear regression. The evaluation criteria of the model were the linear correlation among observed values and those estimated by the model, percentage error, and absolute error.

After the development, calibration and verification of the model, simple bioclimatic scenarios of climate change impacts on the energy balance of the canopy of Jurema preta were produced. The scenarios related to the changes in temperature from canopy and leaf of Jurema preta were based on the most optimistic and pessimistic scenarios presented by IPCC (2007). These included the most optimistic scenario, which has an increase in average air temperature of 1°C, and the worst-case scenario an increase of 3°C.

Results

The soil moisture at 0-10 cm was 10% on average of water content, considered as a soil with low field capacity, meaning that the trees were probably under a maximum transpiration rate.

Figure 3 shows the ratio of daily variations in the average temperatures of the leaf surface, soil surface and air on January 13, 2009. The temperature of the surface of the soil tends to be near the air temperature at the end of the day, and the temperatures of the leaf surface and air showed similar behavior. It was confirmed by the strong relationship between different temperatures; the correlation between the leaf surface temperature of Jurema preta and air temperature (to a level of significance of 0.005) was 92%.
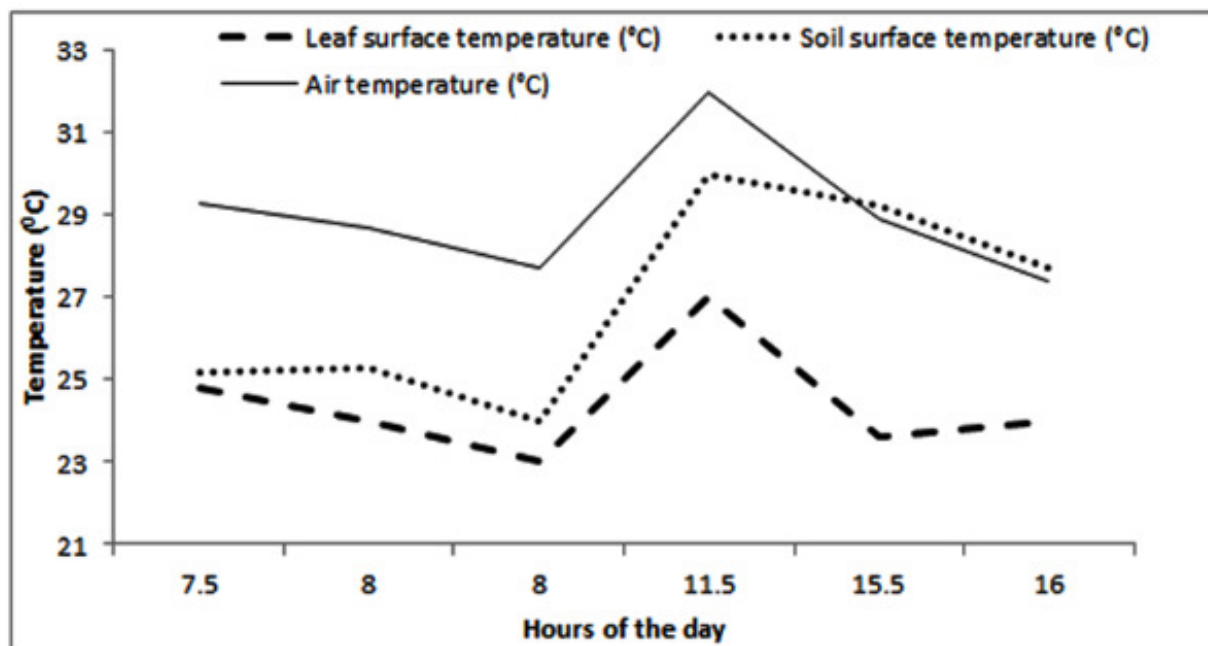

Figure 3. Relationship of daily variations in the average temperatures of the leaf surface, soil surface and air on January 13, 2009.

The daily air temperatures (Figure 4) showed an opposite behavior when compared with the daily relative humidity in the air (Figure 5), and the average daily winds speed oscillated during all day (Figure 6).

On a simulation day, at 09:40 (time according to the imaging satellite Landsat 5 - TM), the weather station, shown in Figure 7A with a black spot, recorded an air temperature of around 28°C while the satellite-based estimation of the surface temperature was 27°C (Figure 7A). The validation of the results of temperature estimated with satellite images can be found in Galvíncio et al. (2009). In the black spot, where the surface temperature was 28°C, the SAVI was, approximately, 0.14, as shown in Figure 7B.
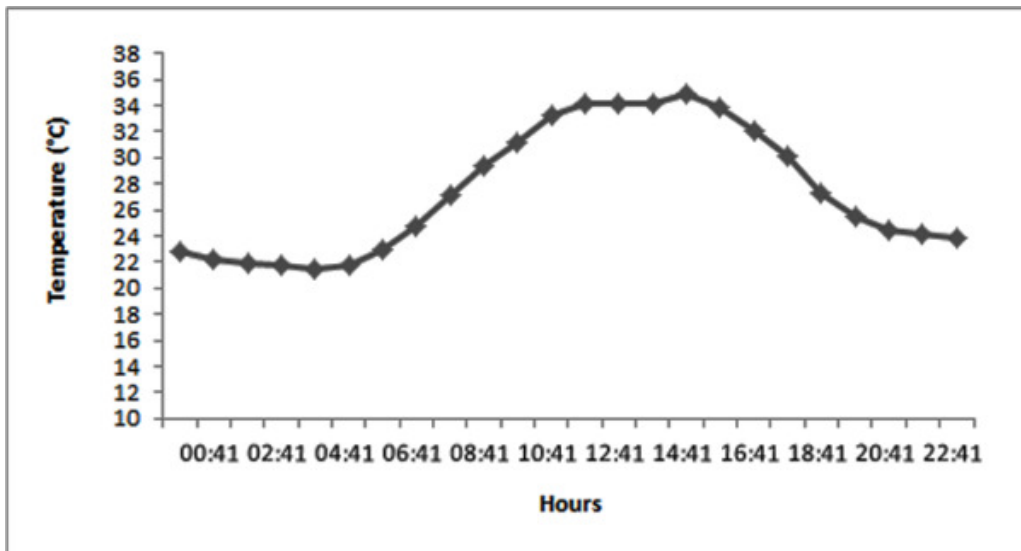
Figure 4. Air temperatures in the municipality of São José do Sabugi-PB on January 13, 2009.
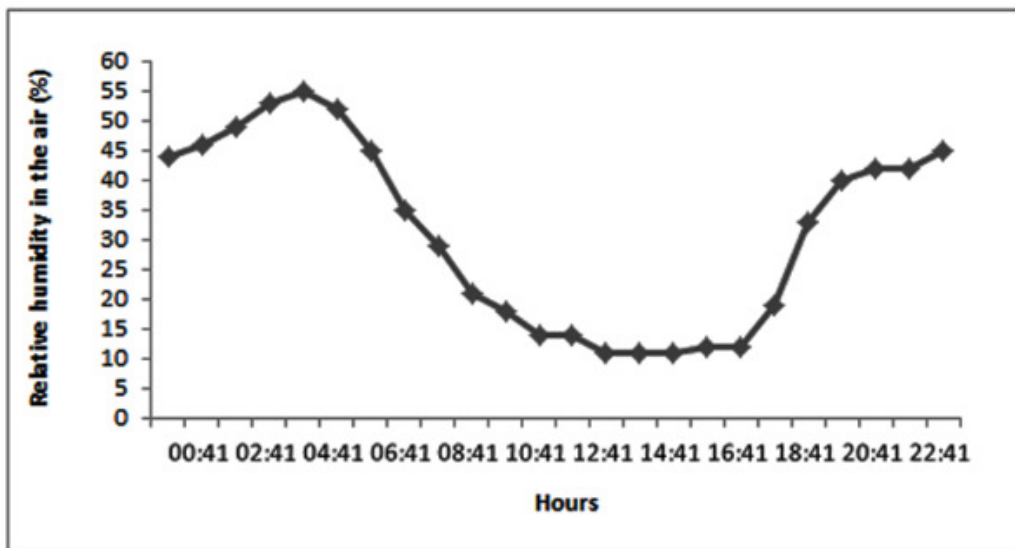

Figure 5. Relative humidity in the air in the municipality of São José do Sabugi-PB on January 13, 2009.
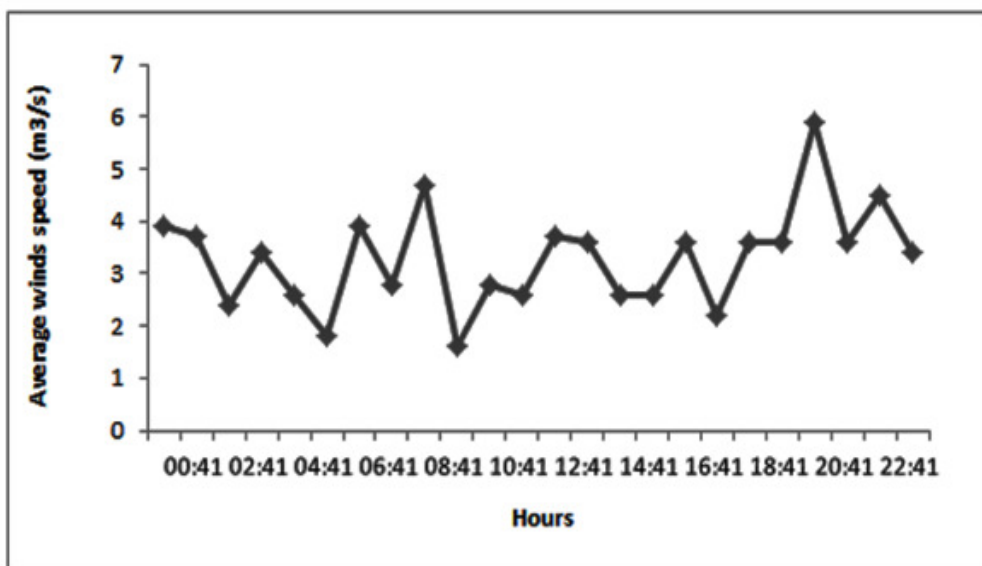

Figure 6. Average wind speed in the municipality of São José do Sabugi-PB on January 13, 2009.

The relationship between the vegetation cover (SAVI) and surface temperature was negative (Figure 7), indicating that higher SAVI values correspond to low temperature values.
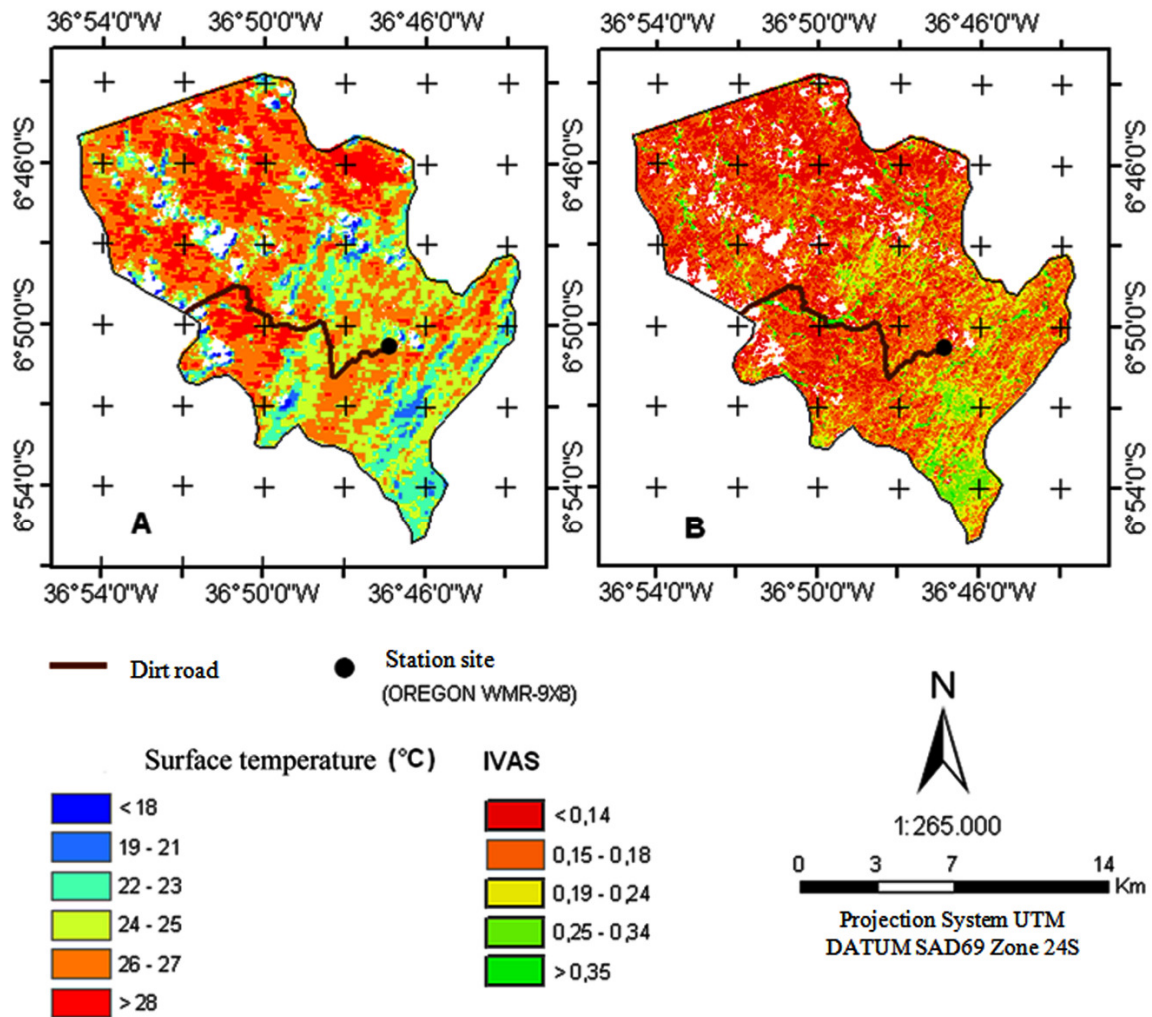

Figure 7. Surface temperature (A) and SAVI (B) in the municipality of São José do Sabugi-PB on January 13, 2009.

According to the observed in the field, this area corresponds to bare soil and grassland. It is possible to see the great visual relationship between the density of vegetation cover and the surface temperature of the canopy. The surface of the soil temperature oscillated between 26ºC and 28ºC; the difference of two degrees was sufficient to produce differences in the landscape.

The regression equation Y = 0.787 X +1.571 was obtained, with R^2 = 0.846, i.e., Tf = 0.787 Ta +1.571, where Tf is the leaf temperature, Ta is the air temperature, and Ta = (Tf-1,571)/0.787.

The values estimated by the model showed a significant relationship with the measured values (Figure 8). Most samples showed regression values below 0.5 (Figure 9).

It is still important to note that the difference between the leaf temperature of Jurema preta and the air temperature was around 5ºC lower in the leaf.

The bioclimatic model here purposed was capable of estimating the surface temperature of the leaf by using the values of air temperature and *vice versa*. The air temperature determined by the model was 29ºC and the value found in the weather station was around 28ºC. Thus, the estimation of this bioclimatic model represents 96% of the observed value or a relative error of 0.04 and an absolute error of 1ºC.

An increase in air temperature of 3ºC would increase the leaf temperature by 2ºC for individuals of Jurema preta growing in the semi-arid conditions, and a 1ºC increase in air temperature would cause a 0.8ºC rising in the leaf temperature of this species.
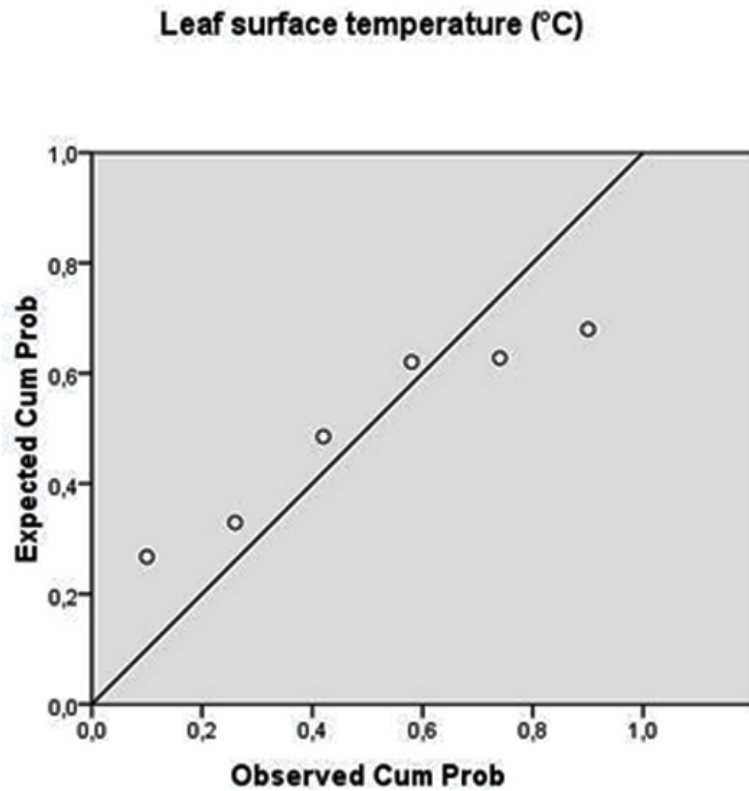
Leaf surface temperature (°C)

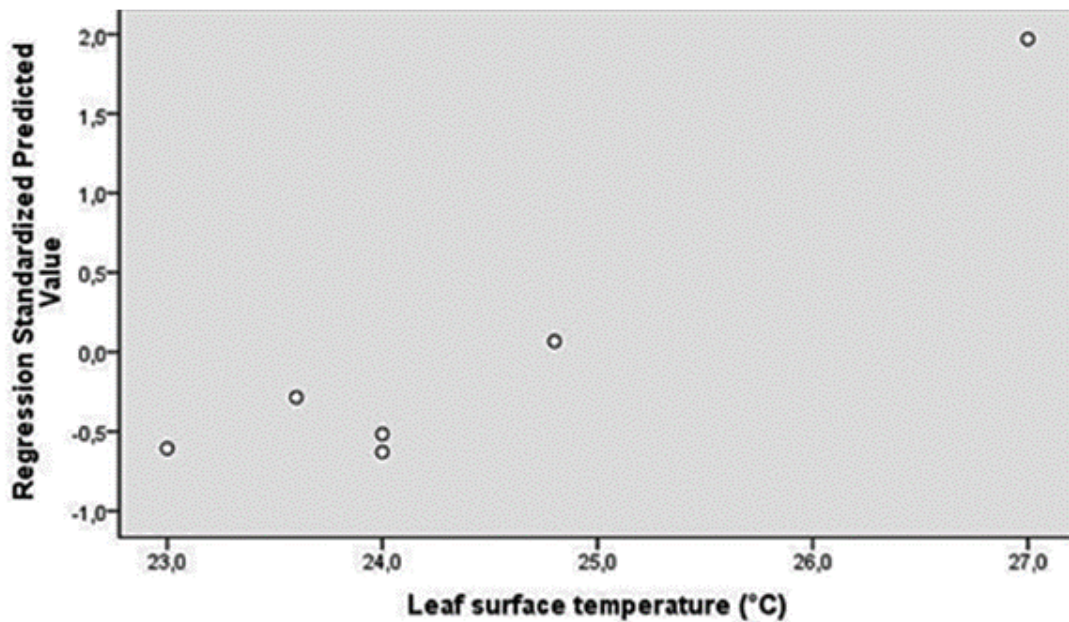Figure 8. The relationship between the observed leaf temperature and that estimated by the model.

Figure 9. The relationship between the estimated values of the regression and the surface temperature of the leaf.

Discussion

Species that can survive in soils under field capacity are considered resistant to severe drought. In general, these species have deep root system capable of absorbing water in the water table.

The opposite conditions between the daily air temperatures oscillation and the daily relative humidity in the air, and the daily average winds speed indicate that, apparently, the winds speed not influenced the water content in the atmosphere, and that the air humidity is related to the air temperature.

Leuzinger & Korner (2007) emphasized the importance of these studies under tropical

conditions. When the difference between the leaf temperature and air temperature is not so high, here it was around 4°C, is expected minimum effects over the physiological mechanisms of the leaf in a plant established under extreme climatic conditions, as in a semi-arid region. It can explain the dominance of this species in that ecosystem.

It was possible to note that this difference of only two degrees in the soil temperature was a result of the coverture of the ground, influenced by the density of individuals of Jurema preta favoring the growth of other small species in the surroundings.

The soil temperature influences the adjacent area nearest the surface of the soil predominantly without altering the air and leaf temperatures.

The evaluating of the relationships between the air and soil temperatures, and between air and leaf temperatures showed best results when using only data from leaf temperature, without including the soil temperature.

Considering the lower temperature in the leaf, around 5°C, in contrast with the air temperature, Pillar (1995) stated that this difference of temperature could reach until 20°C in some plants, and this reduction occurs through the leaf transpiration, stomatal and cuticular. The volume of intercellular spaces, a greater thickness of mesophyll, a higher number of parenchyma cells, reduction of leaf area, and density of stomata, all contribute to maintaining the temperature lower (Wilson & Cooper, 1969; Godoy et al., 2011). As transpiration is a mechanism that permits the water loss by the plant, the apparent lower difference of temperature found in Jurema preta, only 5°C, can be a result of a strategy to reduce the water loss through transpiration. It is shown as an excellent mechanism for plants that must survive in semi-arid environments as in Caatinga (savanna), where high temperature represents a limitation to its surveillance. Leuzinger & Korner (2007) highlighted the importance of the restriction of the temperature differences between plant and air for the achievement of several physiological mechanisms, as photosynthesis, respiration, and transpiration. It is believed that this model can be applied to other species of this biome or similar, mainly those that show similar characters to Jurema preta.

Investigations of water relations, leaf anatomy traits, and air and leaf temperatures indicate that exist a relationship among them; thicker leaves were observed in plants established in environments with highest temperatures (Chabot & Chabot, 1977).

Pillar (1995) stated that the transpiration mechanism maintains the leaf surface temperature with a difference of until 20°C lower about the air temperature. The opening of the stomata regulates the flow of air between the internal leaf structure and the atmosphere, thereby controlling the water loss. The leaf boundary temperature influence and modifies the relationship among stomatal and cuticular transpiration and higher air temperatures, stimulating the cuticle transpiration after the stomatal closure (Pillar, 1995).

The high efficiency obtained in the bioclimatic model corroborates the value found by Gonçalves et al. (2002, unpubl. data) for a region with savanna vegetation in South Africa. It is, therefore, possible to obtain spatially relevant estimations of air temperature from determinations of the surface temperature using satellite images.

Galvíncio et al. (2010) analyzed the relationships between air and soil temperature and chlorophyll a and b for Jurema preta, and stated that when, both, the air and soil temperature increase, chlorophyll a level decrease and chlorophyll b level increase. Although, Klar (1984) reported that the air temperature directly affects the plant growth. Haskell et al. (2012) stated that the effects of the soil temperature on plant growth factors influenced physical, chemical and biological aspects, with direct interference on the processes of organic matter decomposition, nutrient, and water absorption and translocation into the plant. In general, the daily trend of air temperature in the canopy depends on the supply of solar radiation. The layer of leaves where the radiation is intercepted acts as a filter influencing the rate of long-wave radiation loss, the total absorbed energy used for evaporation of water from the soil, the plant transpiration intensity and the turbulent transport of heat in the canopy (Broadbent, 1950). The strata of the canopy that are subject to different and stronger thermal influences can have a greater acceleration of senescence in leaves exposed to higher temperatures (Jochum et al., 2007).

Conclusion

The Jurema preta presents morpho-structural features similar to other dominant species in the Caatinga that are dominant in other areas of the world. The model showed high correlations between leaf temperature and air; the simple and preliminary bioclimatic model showed efficiency for future applications in the regions vegetated with other dominant species, thus contributing to a more efficient monitoring of vegetation under arid environments.

Considering the scenarios projected by this simple bioclimatic model, the greater increase in air temperature and the higher proportion of the leaf temperature, all will act as an inhibitor of

photosynthesis, respiration, and transpiration mechanisms. In the case of occurrence of the IPCC's most optimistic projection, these effects on leaf temperature and its consequences are already critical enough to generate the inhibitions described. New models of scenarios are being developed using a greater amount of weather data and biotic factors, using a larger number of dominant species in tropical arid environmental conditions.

Acknowledgements

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