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Crop Water Stress Index for a medicinal plant (*Baccharis crispa* Spreng.) under variable irrigation levels

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Abstract: There are different techniques for water stress detection in plants and the use of new technologies becomes an essential tool for the development of precision agriculture. One of these technologies is the use of indicators derived from non-contact sensors as infrared thermography. In this study, the *Crop Water Stress Index* (CWSI) was evaluated for a medicinal plant 'carqueja' (*Baccharis crispa* Spreng.), using canopy temperature data obtained with a hand-held infrared thermometer (IRT). The study was carried out under greenhouse conditions at the ESALQ/USP, in Piracicaba, São Paulo State, Brazil. Plants were grown in 11 L pots in a soil classified as Typic Hapludox. The experimental design was completely randomized with 6 blocks and 6 treatments of irrigation levels: 25, 50, 75, 100, 125 and 150% of the reference evapotranspiration (ETo) applied for 180 days. CWSI was calculated with data of leaf temperature and air temperature. The analysis of means was performed by Tukey test at 0.05 probability. It was concluded that treatments under 25 and 50% ETo showed higher leaf temperature and, consequently, higher CWSI, so infrared thermometry can be used as an alternative for the fast and reliable management of irrigation in medicinal plant 'carqueja'.

Keywords: Irrigation scheduling, water stress, infrared thermometry, 'carqueja'.

Índice de estresse hídrico em planta medicinal (*Baccharis crispa* Spreng.) sob níveis variáveis de irrigação

Resumo: Existem diferentes técnicas para a detecção do estresse hídrico em plantas. A utilização de novas tecnologias torna-se uma ferramenta essencial para o desenvolvimento da agricultura de precisão. Uma destas tecnologias é o uso de indicadores derivados das informações técnicas (termografia infravermelha). Avaliou-se o Índice de Estresse Hídrico da Cultura (IEHC) em uma planta medicinal 'carqueja' (*Baccharis crispa* Spreng.), por intermédio do termômetro infravermelho para medir a temperatura foliar das plantas. As plantas foram cultivadas em casa de vegetação na ESALQ/USP, Piracicaba, SP, Brasil, conduzidas em vasos de 11 L cada, em um solo Latossolo Vermelho eutrófico (Typic Hapludox). O delineamento experimental foi em blocos casualizados contendo 6 repetições com 6 tratamentos de lâminas de irrigação: 25, 50, 75, 100, 125 e 150% da evapotranspiração de referência (ETo) aplicadas durante 180 dias. Com os dados de temperatura foliar e de temperatura ambiente, calculou-se o IEHC. Os resultados foram submetidos à análise de variância pelo teste F e as diferenças entre as lâminas foram comparadas pelo teste Tukey em nível de 0,05 de probabilidade. Os tratamentos sob 25 e 50% da ETo apresentaram maior temperatura foliar e os maiores IEHC, conclui-se que a termometria infravermelha pode ser usada como uma alternativa para o manejo rápido e confiável da irrigação nesta planta medicinal.

Palavras-chave: Manejo da irrigação, déficit hídrico, termômetro infravermelho, carqueja.

Introduction

With the increasing demand for water resources and considering the consequences foreseen by the climatic changes as temperatures increase and droughts prolong, is now the development of researches to monitor the water stress in the crops to produce "more harvest per drop". Nevertheless, this challenge can not be achieved without having a comprehensive knowledge of the state of the crop water for proper irrigation management (Taghvaeian et al., 2012). Irrigation scheduling is usually based on methods that determine the meteorological parameters that allow the modeling of evapotranspiration through direct or indirect measurements of soil moisture. Irrigation management considering the state of water stress in the plant is a more advantageous method due to the crop response to both the evaporative demand and the availability of water in the soil (root zone). Consequently, measurements of the plant's water status with infrared hand-held thermometers (IRTs) have become increasingly popular in recent years (Orta et al., 2003) because of their simplicity in collecting data and the low cost of equipment.

It is widely known that temperature, transpiration and water availability to the plant are highly correlated (Hsiao, 1973; Gonzalez-Dugo et al., 2014). Water stress produces an increase in leaf temperature due to stomatal closure. The water stress of the crop is an indicator that was developed based on the normalization of the temperature difference between the canopy (Tc) and the air (Ta) (Jackson et al., 1981; Idso, 1982; Jackson et al., 1988).

The *Crop Water Stress Index* (CWSI) is established on an empirical basis, developed by Idso et al. (1981) to quantify the water stress of crops in arid regions, adopting baseline reference lines without and with water stress. In addition, Jackson et al. (1981) modified CWSI including: vapor pressure deficit (DPV), radiation balance (Rn) and aerodynamic resistance (ra), for a better theoretical prediction of the effects of climate on the temperature of the crop. Therefore, this indicator is based on the canopy and the air temperature difference, measured with infrared thermometer in relation to the evapotranspiration demand measured by the vapor pressure deficit (DPV). The CWSI value, which shows irrigation moment, is crop specific and should take into account factors such as response to water stress, crop value and water cost (Ramirez et al., 2015).

Baccharis crispa Spreng. is a plant with medicinal and aromatic properties known in popular Brazilian medicine as "Carqueja". It is used for stomach disorders, rheumatism, skin wounds and diabetes (Correa et al.,1974; Martinez Crovetto, 1981; De Arruda Camargo, 1985), has diuretic effect (De Arruda Camargo, 1985), and also indicated for hepatic diseases (Toursarkissian, 1980), for body detoxification, as obesity, in hypertension and as anti-inflammatory (Di Stasi et al., 2002; Simões-Pires et al., 2005).

Thus, the objective of this study was to determine the water stress index of the medicinal plant *Baccharis crispa* Spreng. through leaf temperature behavior of plants under different irrigation levels, using a portable infrared thermometer.

Material and Methods

In this assay a botanical material incorporated to the collection of the Herbarium of the Department of Botany of the Federal University of Paraná was registered as UPCB - 86437. A randomized complete block design was used, consisting of 6 treatments and 6 replications, totaling 36 plots. Each plot corresponded to 11 L pot with one "Carqueja" plant.

The experiment was carried out at the experimental area of the Department of Biosystems Engineering "Luiz de Queiroz" College of Agriculture/University of São Paulo, Piracicaba, São Paulo State, Brazil, in greenhouse (22º42'41"S; 47º37'46"W, 561 m elev.) from March 2016 to August 2016. The greenhouse was 6.0 m wide by 24 m in length and 4.0 m high. The ceiling was covered with transparent polyethylene with 150 microns thickness, treated against action of ultraviolet rays and anti-aphid screens. The climate of the region, according to the classification of Köppen (1948), is of the type Cwa, subtropical humid, with drought in the winter and hot and rainy summer. The average temperature of the hottest month is above 22 ° C and the coldest month below 18 ° C (Alvares et al., 2013).

Soil texture in the 20 cm depth was determined at 5 cm depth intervals from soil samples collected at three pots. The soil profile from 0 to 20 cm depth was homogeneous, consisting of approximately 13,4% of clay, 8,5% of silt and 78,1% of sand, with a bulk density equal to 1.54 kg dm^{-3}.

Temperature and relative humidity probes (Campbell Scientific, Logan, UT HMP45C-L), a silicon pyranometer and a cup anemometer (Campbell Scientific 014A-L 3) were used in this study. The data from these instruments were recorded at 15-min intervals, plugged into a datalogger (CR23X Campbell Sci. Ltd., Logan, USA).

A drip irrigation system was used, with discharge rate of 4 L h^{-1} (Naan Daan Jain). The treatments of irrigation were: 25, 50, 75, 100, 125 and 150% of the reference evapotranspiration (ETo) applied throughout the growing cycle, considering a constant crop coefficient of 1,0 during the experimental period. The reference evapotranspiration (ETo) rate (mm day^{-1}) was estimated by the modified FAO Penman-Monteith method (Allen et al., 1998) using data collected by the Campbell Scientific datalogger CR23X installed inside the greenhouse, as follows:

$$ETo = \frac{0.408.s.(Rn - G) + \gamma.900.U_2\left[\frac{es - ea}{Td + 273}\right]}{s + \gamma.(1 + 0.34.U_2)} \quad (1)$$

$$G = 0.38.(T_d - T_{3d}) \quad (2)$$

$$e_s = \left\{\frac{0.6108.e^{[(17.27.Tmáx)\div(237.7+Tmáx)]}}{2} + \frac{0.6108.e^{[(17.27.Tmín)\div(237.7+Tmín)]}}{}\right\} \quad (3)$$

$$e_a = \frac{(UR.e_s)}{100} \quad (4)$$

$$s = \frac{4098.es}{(T + 237.3)^2} \quad (5)$$

Where: ETo is the reference evapotranspiration rate (mm day^{-1}); Rn is the net radiation at the crop surface (MJ m^{-2} day^{-1}); G is the soil heat flux density (MJ m^{-2} day^{-1}); γ is the psychrometric constant (0,063 kPa $°C^{-1}$); Td is the mean daily air temperature at 2 m height (°C), U_2 is the wind speed at 2 m height (m s^{-1}); $(es - ea)$ is the vapor pressure deficit (kPa); s is the slope of vapor pressure curve (kPa $°C^{-1}$).

The crop water stress index was determined based on measurements of "Carqueja" leaf temperature, measured with an infrared thermometer (Kiltherm 500), at a wavelength 670 nm, object distance ratio and measured circumference diameter of 12: 1. For the calculation of the CWSI the difference between the temperature of the crop (Tc) and the air of the crop environment (Ta) was determined, estimated by the equation Jackson et al. (1988):

$$CWS = \frac{(T_c - T_a) - (T_c - T_a)_{LBI}}{(T_c - T_a)_{LBS} - (T_c - T_a)_{LBI}} \quad (6)$$

The estimative of $(Tc - Ta)_{LBI}$ and $(Tc\text{-}Ta)_{LBS}$, for the carqueja crop was performed through empirical equations proposed by Idso et al. (1982), as follows:

$$(T_c - T_a)_{LBI} = 2{,}86 - 1{,}96.DPV \quad (7)$$

$$(T_c - T_a)_{LBS} = 2{,}86 - 1{,}96.(e_s - e_{s+2,86}) \quad (8)$$

Where: DPV is the saturation pressure deficit of water vapor in air, in kPa:

$$DPV = e_s - e_a \quad (9)$$

Where: e_a is the actual vapor pressure, in kPa; e_s the saturation pressure, in kPa, es + 2,86 is the saturated vapor pressure at the air temperature plus the model value for "carqueja" crop which were estimated according to Allen et al. (1998). $(Tc - Ta)_{LBI}$ is the lower temperature baseline, referring to the difference in air temperature for a crop without water stress or referring to wet leaf temperature; $(Tc\text{-}Ta)_{LBS}$ is the upper temperature baseline.

The difference in air temperature was considered when the plant increases without limit canopy resistance to transpiration, corresponding this point to dry leaf temperature. Due to the extreme values of maximum and minimum temperatures recorded in the evaluation period, the values of Ta + 10 °C were analysed to determine Tc by analysing the relation with the soil temperature. As a lower limit the air temperature below 10 °C, with the intention of discarding the cold objects, adapting the proposed intervals according to Meron et al. (2013).

Afterwards, crop water stress index observed ($CWSI_{Observed}$) was substituted, replacing in equation 1 with the lower baseline $(Tc - Ta)_{LBI}$ by the target value as the minimum of the differences between crop temperature observed (Tc) and the mean air temperature (Ta). Upper baseline $(Tc - Ta)_{LBS}$ was obtained as the maximum of the differences. For that, Ta and DPV data of the same time of collection of the temperature of the canopy of each experimental unit were used.

The results were analyzed using ANOVA procedure and Tukey's test was used to determine the mean differences between treatments. All statistical analyses, including the test for homogeneity were performed using the software R studio.

Results and Discussion

During the experimental period, the highest average temperatures of leaves of *Baccharis crispa* Spreng. were recorded in plants under treatments with irrigation levels of 25 and 50% of the reference evapotranspiration (ETo) in March, whose values reached 38.4 and 39.3 °C respectively, being the maximum 41.6 ° C, in the same period. However, plants submitted to irrigation levels 100, 125 and 150% of the reference evapotranspiration (ETo) registered the lowest temperatures, being the minimum on May, with 10.2; 10.1 and 10.4 °C respectively (Figure 1).

During the analysed period the difference between the mean air temperature and the mean leaf temperature increased in the months of July and August for the irrigation level of 50% ETo (Figure 2). For plants submitted to irrigation levels of 100, 125 and 150% ETo, the smallest temperature differences were recorded, the minimum being in April and May months. Similar results were obtained by Sezen et al. (2014) and Ramírez et al. (2015) in red pepper and cherry tomatoes, respectively under conditions of water stress.

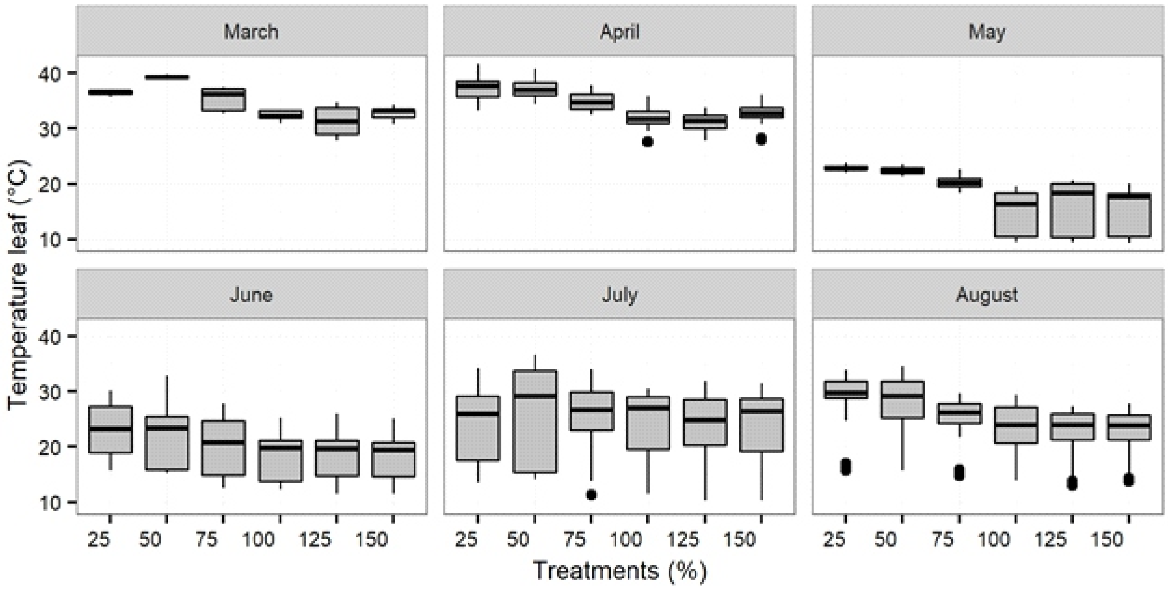

Figure 1. Boxplots with average leaf temperature (°C) for each treatment, separated by month of the year (points indicate outliers).

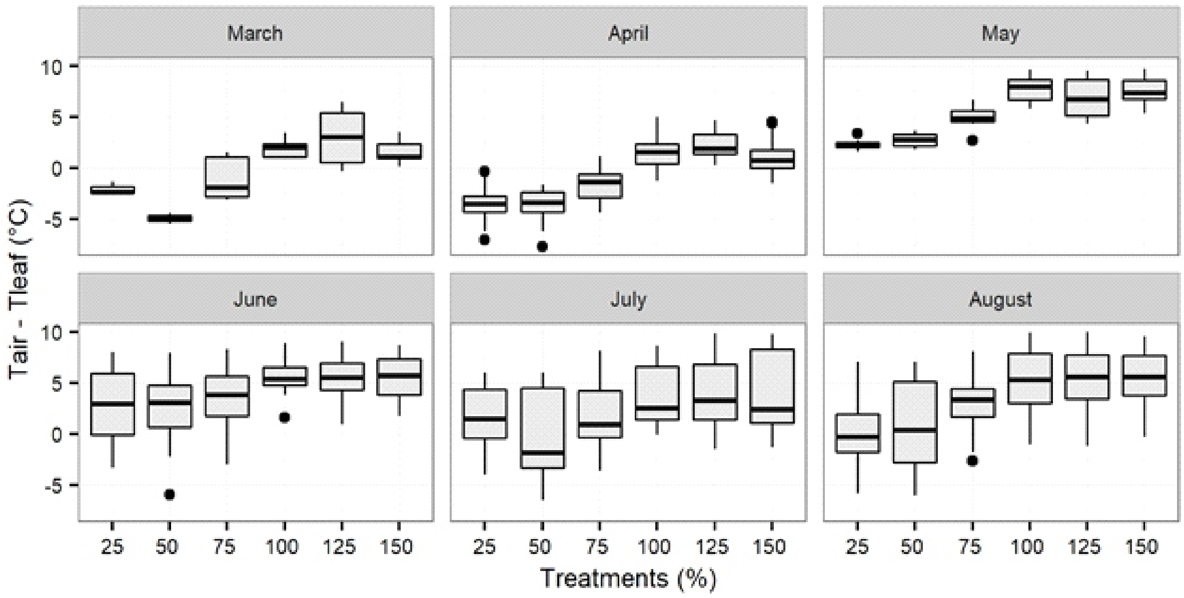

Figure 2. Differences between mean air temperature and the average temperature of the leaf (°C) for each treatment, separated by month of the year (points indicate outliers).

During the first month of the experiment, minimum differences were observed in leaf temperature between treatments, indicating the low variation of vapor pressure deficit (DPV) due to the poor development of *Baccharis crispa* Spreng. canopy area while irrigation treatments were being imposed (Figure 3). In the presence of water stress, plant leaf temperature followed the oscillations of water vapor saturation pressure deficit (Nunes, 2012; Gonzalez-Dugo et al., 2014; Ramírez et al., 2015), being more evident in the treatments 25 and 50% ETo in the month of July, with a range of 0.84 to 2.71 kPa.

In general, the highest variation of CWSI during the analysed period presented a greater variation starting from April month, once the irrigation treatments were established. However, in subsequent months an increasing level of water stress was observed as indicated by canopy temperature and subsequent stress indexes. Figure 4 presents the CWSI for each treatment, separated by month of the year, showing two groups: treatments under water stress (25 and 50% of ETo) throughout the evaluation period. Under treatment of 75% ETo *Baccharis crispa* Spreng. presented characteristics of water stress in March and April,

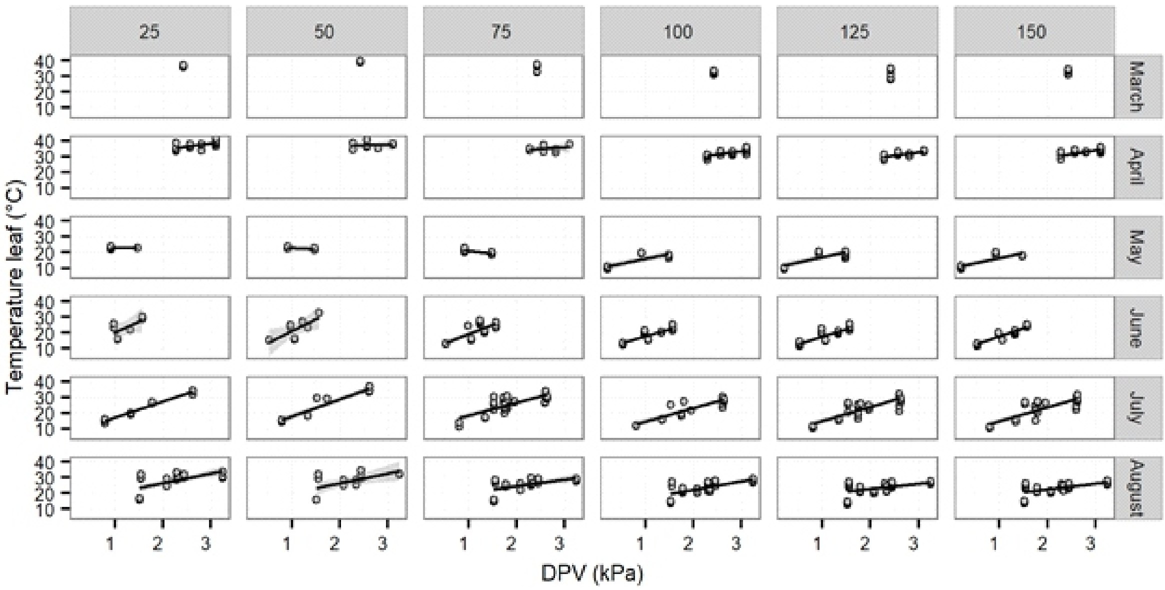

Figure 3. Average leaf temperature (°C) for each treatment, separated by month of the year versus the vapor pressure deficit (kPa) for *Baccharis crispa* Spreng.

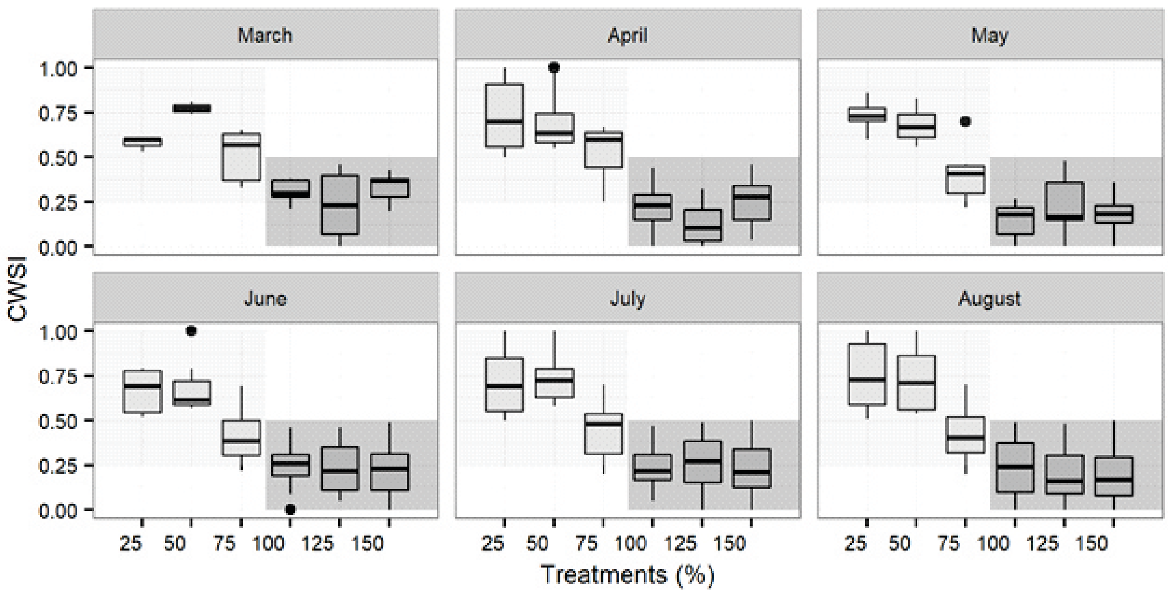

Figure 4. Boxplots of Crop Water Stress Index (CWSI) for each treatment, separated by month of the year. Gray shaded area in figures indicates group of treatments under water satisfaction conditions CWSI $\leq$ 0.50 (points indicate outliers).

Table 1. Analysis of means of the crop water stress index (CWSI) according to the treatments of irrigation (25, 50, 75, 100, 125 and 150 % of the reference evapotranspiration - ETo)

Treatment (%)	25	50	75	100	125	150	CV (%)
CWSI*	0.72 a	0.71 a	0.43 b	0.23 c	0.21 c	0.22 c	22.88%

*Values with the same letter are not significantly different at $p<0.05$, according to Tukey-Kramer HSD test.

possibly at high temperatures recorded in those months. Afterwards, it was considered that plants have adapted to the conditions of water stress belonging to the group of treatments under conditions of water satisfaction CWSI ≤ 0.50.

The relationships between crop water stress index under different treatments of irrigation (Table 1) were all highly significant $p<0.05$. In all cases the highest CWSI values were found in treatments under higher water stress: 25 and 50% ETo. Similar results were obtained for crops: cherry tomato, cowpea, corn, melon, sugarcane, olive and maize (Irmak et al., 1985; Orta et al., 2003; Trentin, 2010; Nunes, 2012; Akkuzu et al., 2013; Bezerra et al., 2014; Dejonge et al., 2015; Ramírez et al., 2015).

Conclusions

Statistical analysis indicated that irrigation treatments significantly affected CWSI.

The results of the study showed that plants submitted to higher water stress (25 and 50% ETo) presented higher leaf temperature (Tc-Ta) than those without irrigation deficit (100, 125 and 150% ETo). The values of CWSI obtained for the plants submitted to the irrigation depth corresponding to 75% of the ETo suggest that they presented a process of adaptation to the water stress.

Independently of the period of the year, canopy temperature determined by infrared thermometry can be a fast, economical and efficient tool to determine the water stress in this medicinal plant.

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