

USO DE SENSORES PROXIMAIS PARA OBTENÇÃO DE NWSB EM VIDEIRAS

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RESUMO: Os Objetivos de Desenvolvimento Sustentável da Organização das Nações Unidas são um apelo para erradicar a fome e promover a agricultura sustentável, portanto, o uso eficiente da água na irrigação é essencial. Torna-se fundamental a utilização eficiente da água nos cultivos irrigados para a conservação do ambiente. As ferramentas de manejo e tomada de decisão para planejamento e monitoramento da irrigação vem sendo aprimoradas com as novas tecnologias advindas da agricultura digital. Entretanto, ainda é necessário monitorar continuamente por meio de sensores de clima, solo e planta as condições hídricas para garantir boa precisão e servir de base para correlações com as novas tecnologias digitais como o uso de imagem termográfica digital. Este estudo tem como objetivo estimar a linha de base inferior (NWSB) do CWSI para uva fina de mesa no estágio de repouso fenológico. Foram avaliados dois pomares, um irrigado e outro não irrigado, localizados no município de São Miguel Arcanjo, SP. Nas duas áreas de estudo foram monitorados dados climáticos, temperatura da copa, umidade e temperatura do solo. Os resultados das NWSB indicam que a cultura está em estresse hídrico mesmo na área irrigada, haja vista que houve baixa precipitação.

Palavras-chaves: Irrigação digital, Sustentabilidade, Tecnologia.

USE OF PROXIMAL SENSORS TO ESTIMATE NWSB IN GRAPEVINES

ABSTRACT: The United Nations Sustainable Development Goals call for the elimination of hunger and the promotion of sustainable agriculture; therefore, the efficient use of water in irrigation is essential. Efficient water use in irrigated cropping systems is fundamental for environmental conservation. Management and decision-support tools for irrigation planning and monitoring have been improved through new technologies emerging from digital agriculture. However, continuous monitoring of plant water status through climate, soil, and plant sensors is still needed to ensure high accuracy and to provide a basis for correlations with emerging digital technologies, such as the use of digital thermographic imagery. This study aims to estimate the nonwater-stressed baseline (NWSB) of the Crop Water Stress Index (CWSI) for fine table grapes during the phenological dormancy stage. Two orchards, one irrigated and one nonirrigated, located in the municipality of São Miguel Arcanjo, São Paulo State, Brazil, were evaluated. In both study areas, climatic data, canopy temperature, and soil moisture and temperature were monitored. The NWSB results indicate that the crop experienced water stress even in the irrigated area because of the low precipitation observed during the study period.

Keywords: Digital Irrigation, Sustainability, Technology.

1 INTRODUCTION

Grapes (*Vitis Grapes (Vitamin vinifera L.)*) are highly important for human consumption and are among the most consumed fruits worldwide. Brazil produced approximately 1.6 million tons annually, with a harvested area of 75,553 hectares in 2022/2023 (EMBRAPA, 2023). Crops are strongly influenced by climate change, especially temperature. Another critical factor affecting grapevine development is spatial variability within vineyards, which can be impacted by the efficient use of irrigation water, particularly when the water needs of a crop are not adequately met.

Efficient water use is essential in grape production, given that the global area cultivated with grapevines exceeds that cultivated with most other fruits (FULTON *et al.*, 2011). Therefore, to improve the efficient use of water in grapevines, it is necessary to implement technologies that allow real-time detection of crop water needs (Han *et al.*, 2018).

The Crop Water Stress Index (CWSI) was developed as a normalized index to quantify stress and overcome the effects of other environmental parameters that influence the relationship between plant stress and temperature (Idso). *et al.*, 1981). The CWSI is based on the relationship between the temperature difference between the canopy and the air ($T_c - T_a$) and the vapor pressure deficit of the air (VPD). For this, it is necessary to estimate the non-water-stressed baseline (NSWSB) and the upper baseline. Notably, accurate estimation of the NSWSB depends on well-irrigated and stress-free plants.

Water stress affects grapevines in several ways, including by reducing their growth, decreasing their productivity, and increasing their susceptibility to pests and diseases. Monitoring the CWSI (citrus wetness index) allows for timely decisions regarding irrigation management. This study aims to estimate the nonwater stress baseline (NWSB) for grapevines during the dormant phenological stage.

2 MATERIALS AND METHODS

The study was conducted in the São Miguel Arcanjo Agrotechnological District, São Paulo State, Brazil, located at coordinates 23°52'42" S and 47°59'50" W, 710 meters above sea level. According to the Köppen–Geiger classification, the predominant climate in the region is type Cfa, temperate, without a dry season and with hot summers. The average annual temperature is 19.2 °C, and the average annual rainfall is 1,454 mm. The soil was classified as a red–yellow argisol with a clayey texture.

The study period spanned from March 18 to August 18, 2025. The phenological development of 'Moscato' cultivar vines was divided into six stages on the basis of days after pruning (DAP), as follows: bud break (15 to 25 DAP); bud break and flowering (26 to 75 DAP); fruit growth (76 to 116 DAP); berry softening (117 to 136 DAP); ripening and harvest (137 to 243 DAP); and phenological dormancy (244 to 365 DAP), completing the crop cycle.

Notably, in the region, pruning is typically carried out in July or early August; therefore, the phenological dormancy stage occurs after maturation and harvesting until pruning.

The Crop Water Stress Index (CWSI) was determined according to the method proposed by Idso. *et al.* (1981), which requires the estimation of the no-water-stress baseline (NWSB) and the upper baseline. This methodology is based on the difference between the canopy temperature (T_c), measured with an infrared thermometer, and the air temperature (T_a), obtained from a weather station and recorded at 20-minute intervals.

An infrared radiometer (IRR) sensor, model SIL411 from Apogee. Instruments were installed in each study area to record the canopy temperature. The devices were connected to a datalogger and installed on March 11 and 12, 2025, in an east–west direction, positioned 50 cm above the plant canopy and with a 30° viewing angle. The upper and lower baselines were established using data from irrigated and nonirrigated vineyard plots.

Climatic data were collected to determine the vapor pressure deficit (VPD), which was calculated from the maximum and minimum air temperature and the maximum and minimum relative humidity, and these data were obtained from the CIIAGRO and INMET meteorological stations located near the experimental sites. For the NWSB adjustment, only data with VPD values below 2 kPa, wind speeds below 6 ms^{-1} , incident solar radiation between 71 and 534 W m^{-2} , and zero precipitation were selected. The time intervals analyzed to evaluate the linear regression behavior ranged from 10:00 AM to 5:00 PM.

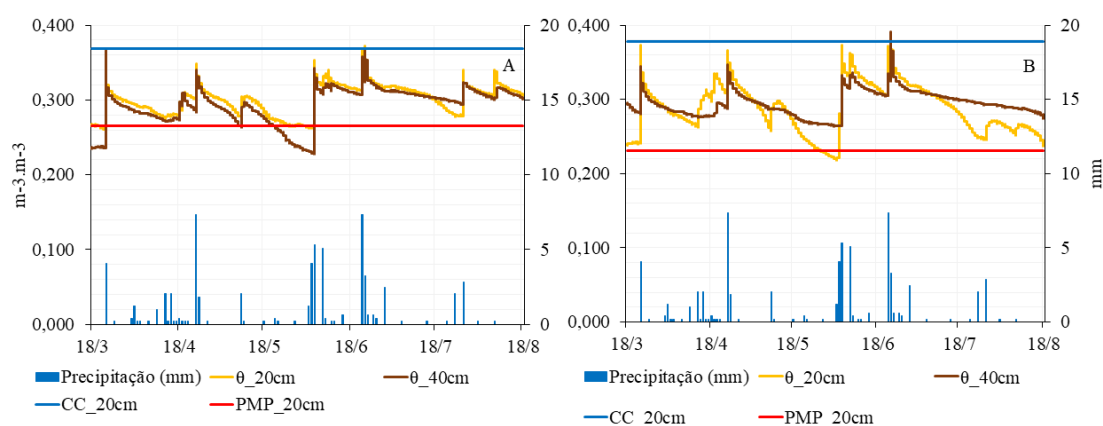
Real-time monitoring of soil moisture, temperature, and electrical conductivity (EC), as well as canopy temperature, was performed with recordings every 20 minutes. To monitor soil variables, five TEROs 12 sensors (METER Group) were installed in both irrigated and nonirrigated areas. Three sensors were positioned at a depth of 0.2 m (one between rows and two in the planting row), and two sensors were installed at a depth of 0.4 cm in the planting row. All the sensors were connected to the ZL6 4G Datalogger, which is responsible for recording and storing the data on a cloud platform with remote access. The Excel® program was used to perform linear regression analyses.

3 RESULTS AND DISCUSSION

The accumulated precipitation during the study period was 78.2 mm, while the potential evapotranspiration (ETp) reached 152.29 mm. The average temperature recorded in São Miguel Arcanjo, SP, was $20.95 \text{ }^\circ\text{C}$.

Soil moisture monitoring data for the study areas are presented in Figure 1. In the irrigated area (Figure 1A), the volumetric water content at a depth of 0.2 m ranged from 0.261 to $0.373 \text{ m}^3 \text{ m}^{-3}$, whereas at 0.4 m, it ranged from 0.229 to $0.366 \text{ m}^3 \text{ m}^{-3}$. From March 24th onward, after approximately 3.47 mm of rainfall, the volumetric water content values at both depths became more similar. In the nonirrigated area (Figure 1B), the volumetric water content at a depth of 0.2 m ranged from 0.220 to $0.390 \text{ m}^3 \text{ m}^{-3}$, and at 0.4 m, it ranged from 0.264 to $0.391 \text{ m}^3 \text{ m}^{-3}$. The field capacity (FC) and permanent wilting point (PWP) at a depth of 0.2 m were 0.369 and $0.266 \text{ m}^3 \text{ m}^{-3}$, respectively, whereas at a depth of 0.4 cm, they were 0.424 and $0.285 \text{ m}^3 \text{ m}^{-3}$, respectively. Irrigation monitoring was based on measurements taken at a depth of 0.2 m along the planting row.

Figure 1. Soil moisture at depths of 0.2 and 0.4 m: (A) irrigated area; (B) nonirrigated area.



In general, the soil moisture behavior was similar at the evaluated depths, although in the nonirrigated area, the moisture at 0.2 m was lower on some dates than at a depth of 0.4 m. Notably, around June 18th, the soil moisture

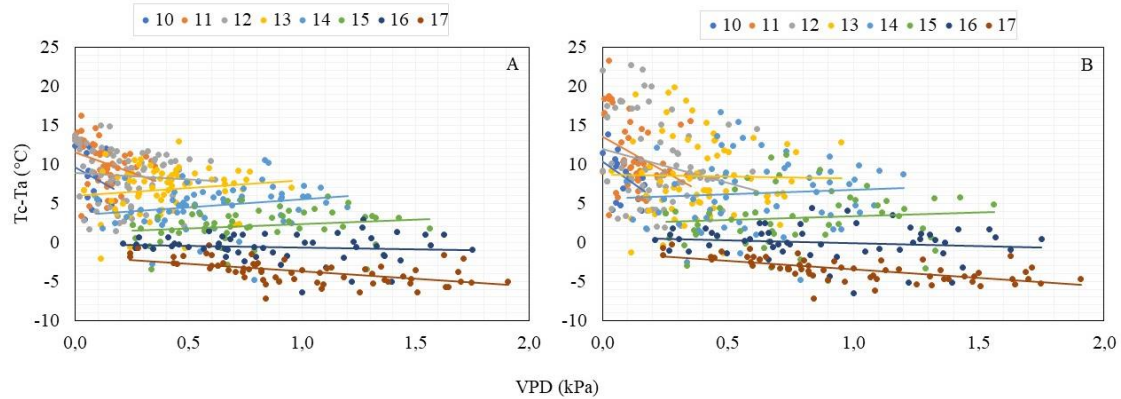
was lower than the moisture at the PMP (plant weight proposition), thus indicating the occurrence of extreme water stress at this stage of the crop. A comparison of the water storage capacity of the irrigated area with that of the

nonirrigated area revealed that the nonirrigated area presented greater storage capacity.

The no-water-stress baseline (NWSB) at different times of day for irrigated and nonirrigated areas is shown in Figure 2. As shown in Figure 2A, the slope of the regression lines varied considerably throughout the day,

with a predominance of positive slopes from 1 pm to 3 pm, indicating that the plant was stressed, while the intercept values progressively decreased during the day. Similar results were reported by Silveira *et al.* (2024), who demonstrated the movement of the intercept throughout the day.

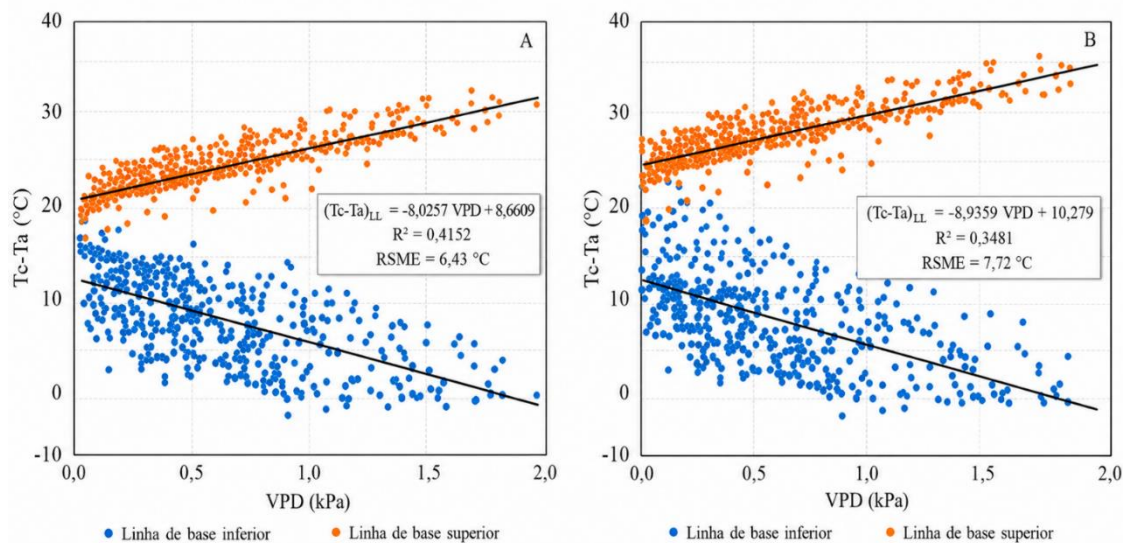
Figure 2. Hourly NWSB in grapevine cultivation: (A) irrigated area and (B) nonirrigated area.



In Figure 2B, the slope was positive between 2 PM and 3 PM, while the intercept also moved throughout the day, a behavior similar to that of the irrigated area.

Notably, in this study, the grapevines were in the dormant phenological stage, a period during which no irrigation was carried out. Therefore, the plants were under severe water stress, as evidenced by the high temperature difference values observed.

The regressions of the lower and upper baselines for irrigated and nonirrigated areas are shown in Figure 3, considering only data with a vapor pressure deficit (VPD) less than 2 kPa, which were collected between 10 am and 5 pm, under a wind speed less than 6 ms^{-1} , incident solar radiation between 71 and 534 W m^{-2} and the absence of precipitation.

Figure 3. NWSB: (A) irrigated area and (B) nonirrigated area.

In the irrigated area (Figure 3A), the linear regression of the NWSB had a slope of $-8.0257 \text{ }^{\circ}\text{C}\cdot\text{kPa}^{-1}$, an intercept of $8.6609 \text{ }^{\circ}\text{C}$, and a coefficient of determination of 0.4152 . For the nonirrigated area (Figure 3B), the values obtained were $-8.9359 \text{ }^{\circ}\text{C}\cdot\text{kPa}^{-1}$, $10.279 \text{ }^{\circ}\text{C}$, and 0.3481 , respectively. Similar results were reported by Bellvert. *et al.* (2015), who reported R^2 values between 0.40 and 0.67 for grapevines, varying according to the phenological stage and the cultivar evaluated.

In the irrigated area (Figure 3A), the upper baseline had a slope of $9.0685 \text{ }^{\circ}\text{C}\cdot\text{kPa}^{-1}$, an intercept of $19.11 \text{ }^{\circ}\text{C}$, and a coefficient of determination of 0.2844 . In the nonirrigated area (Figure 3B), these values were $12.709 \text{ }^{\circ}\text{C}\cdot\text{kPa}^{-1}$, $26.283 \text{ }^{\circ}\text{C}$, and 0.3812 , respectively. The slope in the nonirrigated area was greater, indicating that these plants were under more intense water stress. Furthermore, the higher intercept in the nonirrigated area indicates higher canopy temperatures, reinforcing the stress condition.

This behavior is consistent with the linear regression model developed by Idso (1981), which describes the lower baseline as representative of plants in water comfort, while the upper baseline characterizes plants under severe stress. Thus, during the dormancy period—marked by drought and reduced leaf area—the plants were under significant water stress, indicating that this phenological stage

limits crop development as a function of canopy temperature.

4 CONCLUSIONS

The dormancy phenological stage of the grapevine showed that the plants are subject to water stress resulting from climatic conditions, mainly low air temperature, which limits irrigation at this stage, justifying the absence of irrigation, even in irrigated plots. These factors compromise the determination of the natural water supply system (NWSB); however, these factors may be more appropriate for the phenological stages of full grapevine development. The infrared thermometer used was adequate for obtaining the canopy temperature in the NWSB modeling.

The next steps involved determining the upper and lower baseline values to obtain the cross-water stress index (CWSI) of the 'Moscato' grape cultivar for the remaining phenological stages, namely, bud break, flowering, fruit growth, berry filling, and ripening, to support irrigation management.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

- BELLVERT, J.; MARSAL, J.; GIRONA, J.; ZARCO-TEJADA, PJ Seasonal evolution of crop varieties water stress index in grapevine determined with high-resolution remote sensing thermal imagery. **Irrigation Science** , Heidelberg , vol. 33, no. 2, p. 81-93, 2015.
- EMBRAPA. **National Viticultural Registry** . Brasília, DF: Embrapa, 2023. Available at: <https://www.embrapa.br/uva-e-vinho/cadastro-viticola-nacional?>. Accessed on November 21, 2025.
- FULTON, A.; SCHWANKL, L.; LYNN, K.; LAMPINEN, B.; EDSTROM, J.; PRICHARD, T. Using EM and VERIS technology to assess land suitability for orchard and vineyard development. **Irrigation Science** , Heidelberg v. 29, p. 497-512, 2011.
- HAN, M.; ZHANG, H.; CHAVEZ, JL; MA, L.; TROUT, T.J.; DEJONGE, KC Improved soil water deficit estimation through the integration of canopy temperature measurements into a soil water balance model. **Irrigation Science** , Heidelberg , vol. 36, no. 3, p. 187-201, 2018.
- IDSO, SB; JACKSON, R.D.; PINTER, PJ; REGINATO, RJ; HATFIELD, JL Normalizing the stress-degree-day parameter for environmental variability. **Agricultural Meteorology** , Amsterdam , v. 24, p. 45-55, 1981.
- SILVEIRA, JMC; GÓES, JA; MEADOW, DFS; PIRES, RCM; CHIORATO, AF Baselines for Calculating Crop Water Stress Index in Bean Cultivation. **Remote Sensing and Spatial Information Sciences** , Goettingen , v. 48, p, 501-506, 2024.