

CALIBRAÇÃO E ACURÁCIA DE LEITORES DE TDS EM SISTEMA HIDROPÔNICO DE BAIXO CUSTO

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1 RESUMO

O cultivo hidropônico destaca-se como uma excelente opção para produção agrícola em larga escala de base sustentável e com alto retorno econômico associado. O uso de tecnologias acessíveis que permitam o monitoramento da qualidade da solução nutritiva, contribuem para a ampliação da agricultura hidropônica. Nesse contexto, o uso de sensores de baixo custo para monitoramento da qualidade da solução nutritiva, facilita a automação e permite um maior controle sobre os fatores que interferem no desenvolvimento das plantas. Nesse contexto, o objetivo do trabalho foi calibrar e avaliar o desempenho do sensor TDS-Meter para monitoramento da condutividade elétrica (CE) da solução nutritiva. Durante o ciclo de cultivo da alface hidropônica, a CE da solução foi monitorada por um sensor de bancada (padrão) e pelo sensor alternativo TDS-Meter. Os dados foram utilizados para gerar uma equação de calibração por meio de regressão simples. A qualidade dos dados ajustados foi avaliada mediante a aplicação de índices estatísticos. A calibração do sensor TDS-Meter potencializou o uso desse equipamento em sistemas de monitoramento de solução nutritiva de baixo custo para cultivos hidropônicos. A equação de calibração melhorou a capacidade de predição dos valores de condutividade elétrica.

Palavras-chave: Condutividade elétrica, precisão, solução nutritiva.

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**CALIBRATION AND ACCURACY OF TDS READER IN LOW-COST
HYDROPONIC SYSTEM**

2 ABSTRACT

Hydroponic cultivation stands out as an excellent option for large-scale agricultural production on a sustainable basis and with a high associated economic return. The use of accessible technologies that allow monitoring of the quality of the nutrient solution contributes to the expansion of hydroponic agriculture. In this context, the use of low-cost sensors for monitoring the quality of the nutrient solution facilitates automation and allows greater control over the factors that interfere with plant development. In this context, the objective of this work was to calibrate and evaluate the performance of the TDS-Meter sensor for monitoring the electrical conductivity (EC) of a nutrient solution. During the hydroponic lettuce cultivation cycle, the EC of the solution was monitored by a benchtop sensor (standard) and an alternative TDS-Meter sensor. The data were used to generate a calibration equation through simple regression. The quality of the adjusted data was evaluated by applying statistical indices. The calibration of the TDS-Meter sensor enhanced the use of this equipment in low-cost nutrient solution monitoring systems for hydroponic crops. The calibration equation improved the prediction ability of the EC values

Keywords: Electrical conductivity, accuracy, nutrient solution.

3 INTRODUCTION

In the face of adverse climate conditions, it is highly important to develop and improve techniques to intensify sustainable production, always seeking to rationalize the use of natural resources and ensure the profitability of agricultural production. In this context, hydroponic cultivation is a promising alternative that can address environmental and food issues, allowing farmers to rationalize inputs and optimize crop growth (Richa; Fizir; Touil, 2021). In this cultivation system, monitoring factors such as pH, electrical conductivity (EC), and nutrient concentration of the nutrient solution is essential to ensure the health and good development of the plants. In accordance with Jung *et al.* (2019), the quality of a nutrient solution is normally assessed by monitoring the EC.

The use of automation in hydroponic crops is essential to guarantee the efficiency of the system, ensuring constant monitoring of these nutrient absorption levels and avoiding possible nutritional imbalances. In this context, Cambra *et al.* (2018) state that

the automation of irrigation processes through low-cost sensors can disseminate technological advances in a sector that is heavily influenced by economic costs. Cunha *et al.* (2020) highlighted the importance of developing multiparameter devices on the basis of more accessible platforms and sensors, as well as the use of technologies that facilitate data collection and access. Thus, low-cost sensors stand out as an alternative to benchtop sensors because, in addition to being more economical, they are more portable, allowing the transportation and collection of data in the field. In addition, they enable integration with automation systems and the Internet of Things (IoT).

In terms of data collection, Arduino software stands out as a promising tool, as it is an accessible and open-source platform, allowing the development of measurement and control devices. (Zafar *et al.*, 2018). However, these alternative sensors must provide accuracy and reliability in their readings. Thus, the objective of this work was to calibrate the TDS-Meter sensor (low cost) and analyze its operation for

monitoring electrical conductivity in a hydroponic system.

4 MATERIALS AND METHODS

The experiment was conducted at the Center for Agricultural and Biodiversity Sciences (CCAB) of the Federal University of Cariri (UFCA) in Crato, CE, Brazil (7°14'08" S latitude and 39°22'07" W longitude, altitude of 420 m). The Hydrology and Hydraulics and Physiology and Biochemistry of Plant Stress laboratories were used as support points for the assembly of the monitoring and data reading system with standard equipment.

Data collection took place during the lettuce cultivation cycle in a hydroponic system from March 7 to 27, 2024. To monitor the electrical conductivity of the nutrient solution, TDS-Meter (Analog Water Conductivity Sensor) equipment was used, which provides readings of the concentration of dissolved solids in the solution.

The following hardware items were used: Arduino Uno, a microcontroller based on Atmega 3228, an LCD display, a protoboard and resistors. As software, Arduino IDE was used to develop the device reading and data processing programming. Initially, following the manufacturer's recommendation, the calibration equation that relates the voltage measured by the sensor with the actual total dissolved liquid (TDS) values was determined via the following steps: collected from voltages in low-conductivity (84 $\mu\text{S cm}^{-1}$) and high-conductivity solutions (1408 $\mu\text{S cm}^{-1}$); subsequently, the correction factor (CF) was calculated via Equation (1).

$$FC = \frac{TDS_{Alto} - TDS_{Baixo}}{Tensão_{Alto} - Tensão_{Baixo}} \quad (1)$$

Where TDS_{High} and TDS_{Low} represent the TDS values of the high- and low-conductivity solutions, respectively. Voltage_{High} - Voltage_{Low} are the voltage

readings corresponding to the mentioned solutions.

After this process, the sensor was properly installed inside the reservoir of the nutrient mixture intended for the cultivation of curly lettuce (*Lactuca sativa*). This made it possible to monitor electrical conductivity in real time. Data collection in the field occurred during the 21-day period, corresponding to the vegetative development cycle of lettuce. Monitoring was performed daily, always at the same time (at 9:00 am) by the standard sensor (benchtop - Oakton/Eutech CON 700 model) and by the alternative TDS-Meter sensor.

The alternative sensor (TDS-Meter) readings were calibrated in relation to the standard sensor (bench) via polynomial regression, in which the choice of the model that best adjusted the data were based on the highest value of the coefficient of determination (R^2). The analysis of the results was performed by means of a 1:1 straight line comparison between the alternative and standard data and by applying the following statistical indices: mean error (ME), which indicates the accuracy of the estimate; the root mean square error (RMSE), which quantifies the dispersion of the values around the 1:1 reference line; the Willmott concordance index (d), which is a standard measure for the model's estimation error; the Pearson correlation coefficient (r), which allows quantification of the association between the analyzed variables; and the confidence index (c), which was proposed by Camargo and Sentelhas (1997), according to equations (2) and (6), respectively.

$$EM = \frac{1}{n} \sum_{i=1}^n (P_i - O_i) \quad (2)$$

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^n (O_i - P_i)^2 \right]^{0,5} \quad (3)$$

$$d = 1 - \left[\frac{\sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (|P_i - \bar{O}| + |O_i - \bar{P}|)^2} \right] \quad (4)$$

$$r = \frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{\sum_{i=1}^n [(O_i - \bar{O})^2]^{0.5} [(P_i - \bar{P})^2]^{0.5}} \quad (5)$$

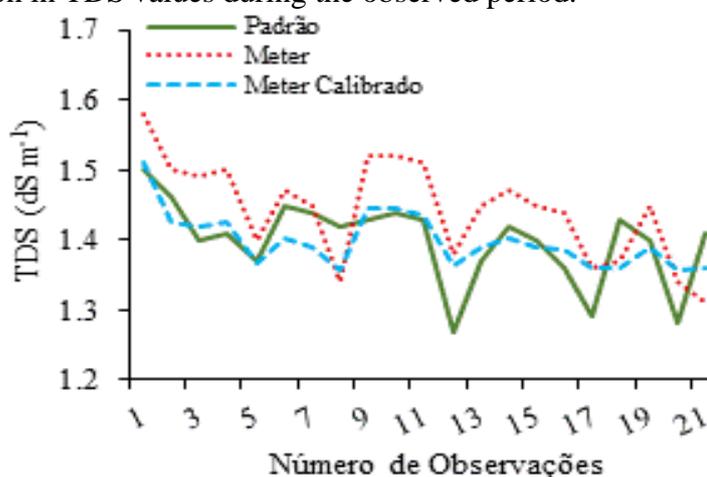
$$c = d \times r \quad (6)$$

Where EM – mean error; Hi – standard data; Pi – alternative data; n – number of pairs of standard and predicted data; RMSE – root mean square error; Hi – standard data; Pi – alternative data; n – number of pairs of standard and predicted data; d – Willmott's concordance index; \bar{O} – mean of standard data; r – correlation coefficient; and ec – coefficient of performance.

5 RESULTS AND DISCUSSION

From the electrical conductivity data obtained by the bench sensor (Oakton/Eutech CON 700 - TDS standard) and the alternative sensor (TDS-Meter), curves were generated to evaluate the TDS behavior of the nutrient solution used during the hydroponic cultivation period of the lettuce crop (Figure 1).

Figure 1. Variation in TDS values during the observed period.



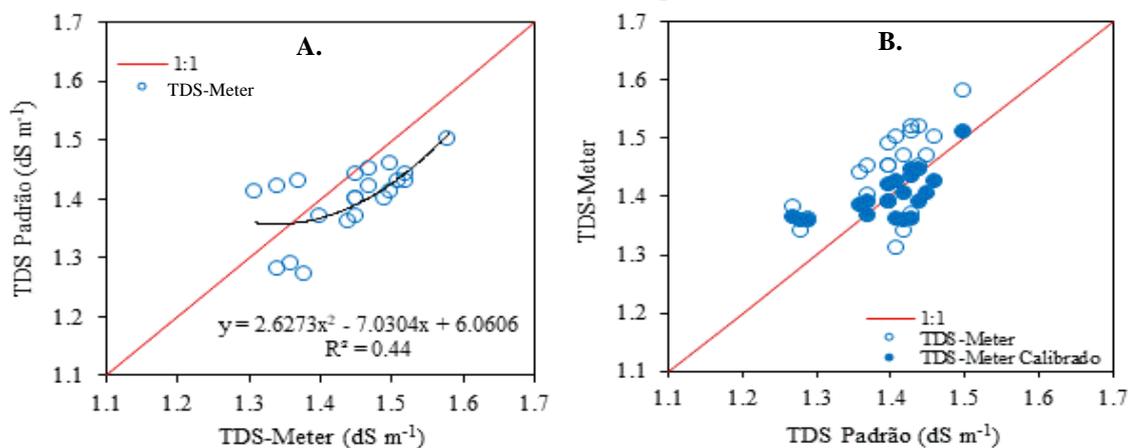
Source: Authors (2025)

The reading range obtained by the TDS-Meter sensor before calibration was from 1.31 to 1.58 dS m⁻¹, and after calibration, it was from 1.36 to 1.51 dS m⁻¹. Within the reading range of the TDS-Meter sensor before calibration, there was a tendency to overestimate the standard values and not follow the peaks of lower values (Figure 1). After calibration of the sensor, a greater approximation of the alternative values with the standard values is noted; however, even the TDS-Meter sensor was not able to follow the peaks of lower values.

The calibration equation for the electrical conductivity sensor was obtained by correlating the TDS values obtained by

the standard sensor and the alternative sensor (TDS-Meter) (Figure 2A). The model that fit the data were the polynomial with an R² of 0.44. The alternative TDS sensor (TDS-Meter) before calibration overestimates the standard values in the reading range of 1.40 to 1.58 dS m⁻¹, which corresponds to the standard range of 1.37 to 1.50 dS m⁻¹ (Figure 2B). After calibration, the sensor showed greater reading accuracy, with values closer to the 1:1 line; however, it tended to overestimate at lower values (equal to or lower than 1.42 dS m⁻¹), conferring low reading sensitivity at these concentrations.

Figure 2. Calibration equation obtained by correlating the TDS standard values and the TDS-Meter sensor values (A), and TDS values obtained by the TDS-Meter sensor before and after calibration, correlated with the respective standard values (B).



Source: Authors (2025)

According to Jiménez *et al.* (2019), laboratory calibration of alternative (low-cost) sensors significantly improves the accuracy of readings. Calibration did not significantly affect the RMSE value, which was already considered low and was reduced by an additional 43%; however, its performance was considered “Terrible” and

evolved only to “Poor” (Table 1). This result may be associated with the uncertainties associated with the model chosen for data calibration, which may be influenced by the short data series analyzed. Passos *et al.* (2023) obtained an RMSE value of 165.14 for TDS, which, according to the author, represents low data accuracy.

Table 1. Statistical indices for the TDS sensor (TDS-Meter) before and after calibration

| Sensor | Indices | | | | | | |
|----------------------|---------|----------------|------|------|-------------|------|--------|
| | r | R ² | D | c | Performance | RMSE | IN |
| TDS-Meter | 0.62 | 0.39 | 0.34 | 0.21 | Terrible | 0.07 | -0.04 |
| Calibrated TDS-Meter | 0.67 | 0.44 | 0.76 | 0.51 | bearable | 0.04 | 0.0001 |

The Wilcoxon concordance index (d) improved significantly after calibration, indicating good agreement between the standard values and those obtained by the alternative sensor after calibration. A similar situation occurred with the EM values, where for the alternative TDS sensor after calibration, the EM value approached zero. In this regard, Passos *et al.* (2023) obtained a d index of 0.95 for TDS, which is superior to the results obtained in this study. Pangestu, Sani and Mutiara (2023), evaluating the calibration of a TDS sensor, obtained error rates ranging from 19--41 for TDS. The calibration of the pH and TDS

sensors also improved the correlation (r values of 0.85 and 0.67) between the values obtained by the standard equipment and the values obtained by the alternative sensor, resulting in an increase in the R2 value. Therefore, the calibration effectively improved the precision and accuracy of the alternative TDS sensor.

In general, portable sensors that have low acquisition costs are functional and indispensable equipment in hydroponic production systems. The TDS-Meter sensor allows monitoring of the EC of the nutrient solution; however, it is also necessary to pay attention to details such as cleaning the

sensor after use with deionized water, calibrating it regularly and checking the results with standard sensors to maintain the accuracy of the readings and the integrity of the sensor.

6 CONCLUSIONS

Calibration of the TDS-Meter sensor has increased the use of this equipment in low-cost nutrient solution monitoring systems for hydroponic crops. The calibration equation improved the prediction capacity of the EC values. Its use without prior calibration is not recommended. The electrical conductivity values obtained by the alternative sensor after calibration correlate with the values obtained by the standard equipment.

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