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USE OF LOW-COST SENSOR AS AN ALTERNATIVE FOR PH MONITORING IN HYDROPONIC SYSTEM**USO DE SENSOR DE BAIXO CUSTO COMO ALTERNATIVA PARA MONITORAMENTO DE PH EM SISTEMA HIDROPÔNICO**

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ABSTRACT: Hydroponics has become increasingly popular due to its production potential and for offering several advantages such as efficient use of water and use of reduced space for cultivation. However, to ensure proper functioning of this system, monitoring some parameters, such as the pH of the solution, is indispensable. Data were collected during the growing cycle of hydroponic lettuce. The alternative pH sensor (pH-4502C) was calibrated relative to simultaneous readings with a standard sensor (benchtop), by means of polynomial regression, and the model that best fitted the data was chosen based on the highest value of the coefficient of determination (R²). The calibration equation showed R² of 0.72, and significantly improved the accuracy of the sensor, reducing the RMSE value by 30%, making its performance change from “average” to “very good”. The calibration of the pH sensor (pH-4502C) enhanced its use in low-cost nutrient solution monitoring systems for hydroponic cultivation. The calibration equation improved the capacity of the sensor to predict pH values, so its use without prior calibration is not recommended.

KEYWORDS: *Nutrient solution, accuracy, calibration.*

RESUMO: A hidroponia tem se tornado cada vez mais popular devido ao seu potencial produtivo, e por oferecer diversas vantagens como o uso eficiente da água e a utilização de espaços reduzidos para o cultivo. Entretanto, para garantir o funcionamento adequado desse sistema, o monitoramento de alguns parâmetros, como o pH da solução, é indispensável. Os dados foram coletados durante o ciclo de cultivo de alface hidropônica. A calibração do sensor alternativo de pH (pH-4502C) foi realizada em relação a leituras simultâneas por um sensor padrão (bancada), por meio de regressão polinomial, no qual a escolha do modelo que melhor se ajustou aos dados baseou-se no maior valor do coeficiente de determinação (R²). A equação de calibração apresentou R² de 0,72, e melhorou significativamente a exatidão do sensor, reduzindo em 30% o valor do RMSE fazendo com que o desempenho passasse de “mediano” para “muito bom”. A calibração do sensor de pH (pH-4502C) 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 pH. Não sendo recomendado seu uso sem calibração prévia.

PALAVRAS-CHAVE: *Solução nutritiva, acurácia, calibração.*

INTRODUCTION

Hydroponics is a technique of cultivation in a water environment, which depends on nutrient solution to provide the necessary nutrients for plants. However, to ensure proper functioning of this system, variables such as dissolved oxygen (DO), temperature, pH, and electrical conductivity (EC) must be considered (LEE et al., 2017; SAMBO et al., 2019; KHAN et al., 2020). pH is directly related to the absorption of nutrients by plants, so that changes in the pH level occur as a function of the difference in the magnitude of nutrients absorbed, depending on the balance between anions and cations (ASAO, 2012).

Thus, automation of hydroponic cultivation is an alternative to ensure better system functioning, ensuring constant supervision of parameters such as pH, to avoid possible nutritional imbalances that could affect production (SENA et al., 2023). In this context, Cunha et al. (2020) emphasize the relevance of developing multiparameter devices based on more accessible platforms and sensors, as well as using technologies that facilitate data collection and access.

In this context, low-cost sensors emerge as an alternative to benchtop sensors, because in addition to being more accessible, they have greater portability, allow the monitoring of the nutrient solution, with easy installation, and enable the creation of versatile and accessible systems (LOPES; PIRES; SERRA, 2018; SOUSA; ROCHA, 2020; SILVA; SILVA JÚNIOR, 2021). In addition, they allow integration with automation systems that connect through the basic premises of the Internet of Things (IoT) (TALAVERA et al., 2017). In terms of information processing, the Arduino software presents itself as a promising tool, as it is an accessible platform and has open source for developing measurement and control devices (ZAFAR et al., 2018). However, for monitoring the concentrations of the nutrient solution, the sensor needs to be accurate.

Considering that the low-cost sensor does not have the same precision as the benchtop pH meter, it is important to perform

its calibration and verification, so that its use is reliable. In this context, this study aims to perform the calibration of the alternative pH-4502C sensor, analyzing its operation for pH monitoring in a hydroponic system.

MATERIAL AND METHODS

The study was conducted at the Center for Agrarian Sciences and Biodiversity (CCAB) of the Federal University of Cariri (UFCA) in Crato, CE, Brazil, (7°14'08"S latitude and 39°22'07"W longitude, altitude 420 masl). The monitoring and data collection system was set up in the laboratories of Hydrology and Hydraulics and Physiology and Biochemistry of Stress in Plants.

Data collection was carried out *in situ*, during the lettuce crop cultivation cycle in a hydroponic system from March 7 to 27, 2024. The pH of the nutrient solution was monitored using the pH-4502C instrument (pH Sensor Electrode Probe). The following hardware items were used: Arduino uno, microcontroller based on Atmega 3228, LCD display, protoboard and resistors. As software, Arduino IDE was used to develop the programming for device reading and data processing.

According to the manufacturer's recommendation, the calibration equation that relates the voltage measured by the sensor to the actual pH values was determined by collecting the voltages by the pH sensor in pH 2 and pH 10 buffer solutions. These voltages were used to generate an equation for converting the voltage readings to pH readings. After this process, the sensor was properly installed inside the reservoir of the nutrient solution intended for the cultivation of leaf lettuce (*Lactuca sativa*), enabling real-time monitoring of its pH. In the evaluation of the pH meter performance, only readings taken always at 9:00 a.m. were considered. A sample of the nutrient solution was taken from the reservoir and sent to the laboratory for pH measurement using a benchtop instrument (Quimis model), which is considered standard. The pH readings obtained by the alternative pH-4502C sensor and by the standard

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instrument were recorded and stored for further analysis.

The calibration of the readings of the alternative sensor (pH-4502C) relative to the standard sensor (benchtop) was performed by means of polynomial regression, and the model that best fitted the data was chosen based on the highest value of the coefficient of determination (R²). The results were analyzed by comparing the alternative and standard data with a 1:1 line and by applying the following statistical indices: mean error (ME), which indicates the accuracy of the estimate, root mean square error (RMSE), which quantifies the dispersion of the values around the 1:1 reference line, the Willmott's index of agreement (d), which is a standard measure for the estimation error of the model, Pearson's correlation coefficient (r), which allows quantifying the association between the variables analyzed, and the confidence index (c) proposed by Camargo and Sentelhas (1997), described in Equations 1 to 5.

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

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

$$d = 1 - \left[\frac{\sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \right] \quad (3)$$

$$r = \frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{[\sum_{i=1}^n (O_i - \bar{O})^2]^{0,5} [(P_i - \bar{P})^2]^{0,5}} \quad (4)$$

$$c = d \times r \quad (5)$$

Where: ME – mean error; O_i – standard data; P_i – alternative data; n – number of standard and predicted data pairs; RMSE – root mean square error; O_i – standard data; P_i – alternative data; n – number of standard and predicted data pairs; d – Willmott's index of agreement; \bar{O} – average of standard data; r – correlation coefficient; c – performance index; and d – Willmott's index of agreement. The performance index (c) can be interpreted as follows: terrible ≤ 0.40 ; very poor, 0.41 to 0.50; poor, 0.51 to 0.60; average, 0.61 to 0.65; good, 0.66 to 0.75; very good, 0.76 to 0.85; and excellent, 0.85 > (CAMARGO; SENTELHAS, 1997).

RESULTS AND DISCUSSION

From the pH data obtained by the standard Quimis sensor and by the alternative pH-4502C sensor, curves were generated to evaluate the behavior of pH in the nutrient solution used in the hydroponic cultivation of lettuce.

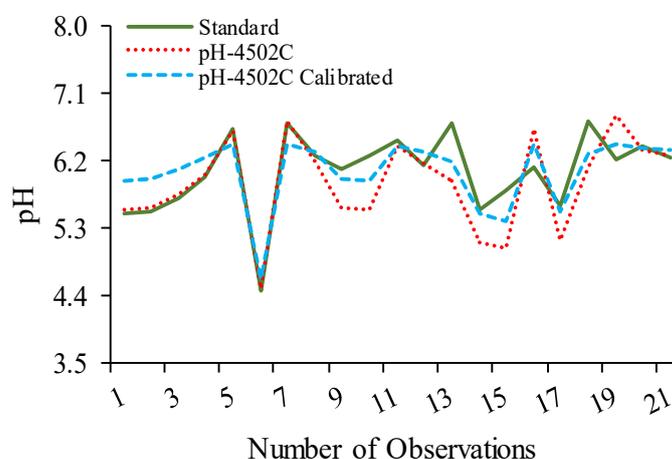


Figure 1. Variation in pH values during the observed period.

The reading range estimated by the pH-4502C sensor is 4.50 to 6.81 before calibration and 4.62 to 6.43 after calibration. The pH values obtained before calibration did not tend to overestimate or underestimate the values obtained by the standard sensor until the 8th day of observation, but from the 9th day onwards there was a tendency to underestimate the standard readings, with peaks of overestimates (Figure 1).

After calibration, the values were closer to the standard, but there was a tendency to underestimate the readings in the first days of analysis. Thus, for single analyses or short observation periods of up to eight days, it is considered that there is no need for calibration.

The calibration equation was generated by correlating the pH values obtained by the standard sensor and the alternative sensor (pH-4502C) (Figure 2A). The model that had the

best fit was the second-degree polynomial with R2 of 0.72, considered as “good”, which gives greater reliability to the results.

When studying the performance of the pH sensor (pH-4502C model) for monitoring irrigation water quality, Passos et al. (2023) obtained R2 of 0.93 in the calibration equation. Saputra (2024) calibrated the pH sensors (pH-4502C model) for monitoring the nutrient solution in hydroponic cultivation and obtained R2 of 0.86.

The alternative pH sensor (pH-4502C) before calibration showed greater dispersion of values, moving away from the 1:1 line (Figure 2B). After calibration of the pH-4502C sensor, the pH values corrected by the specific equation were closer to the values obtained by the standard instrument (approaching the 1:1 line), indicating greater data accuracy. However, readings below pH 6.0 tended to overestimate the standard values.

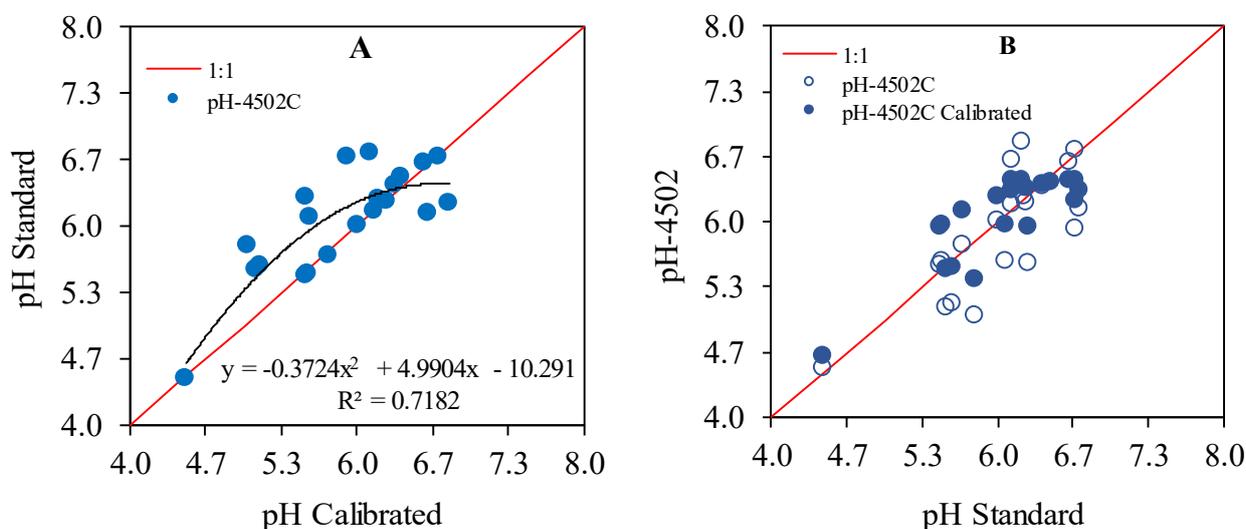


Figure 2. Standard pH values (A) correlated with values obtained by the pH-4502C sensor (A). pH values obtained by the pH4502C sensor before and after calibration, correlated with the respective standard values (B).

According to Meza et al. (2022), by performing a well-designed sensor calibration, it is possible to achieve accurate readings in pH determination by alternative sensors. The calibration of the pH-4502C sensor

significantly improved its accuracy, reducing the RMSE value by 30%, making the performance change from “average” to “very good” (Table 1).

Table 1. Statistical indices for the pH sensor (pH-4502C) before and after calibration

Sensors	Indices						
	r	R ²	d	c	Performance	RMSE	ME
pH-4502C	0,80	0,63	0,82	0,65	Average	0,40	0,15
pH-4502C Calibrated	0,85	0,72	0,91	0,77	Verygood	0,28	-0,002

Passos et al. (2023), when evaluating the calibration of the pH sensor pH-4502C, obtained RMSE values of 1.18 and performance classified as “Excellent” (c = 0.95).

It is worth noting that the pH-4502C sensor has automatic ambient temperature compensation, which favors its best performance. It was observed that the Wilmott’s index of agreement (d) improved significantly after calibration, obtaining a value above 0.90, which indicates good agreement between the values obtained by the alternative and by the standard sensor. The same occurred with the ME values, which were close to zero.

Calibration also improved the correlation (r) between the values obtained by the standard and by the alternative sensor, which resulted in an increase in the R² value, indicating that calibration improved the precision and accuracy of the alternative pH sensor reading. Pangestu et al. (2023) obtained error rates ranging from 0.19 to 0.44 for pH.

CONCLUSIONS

The calibration of the pH sensor (pH-4502C) enhanced its use in low-cost nutrient solution monitoring systems for hydroponic cultivation.

The calibration equation improved the capacity of the sensor to predict pH values, so its use without prior calibration is not recommended.

The pH values obtained by the alternative sensor after calibration correlate with the values obtained by the standard instrument.

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