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CALIBRAÇÃO E AVALIAÇÃO DE SENSORES DE UMIDADE DO SOLO PARA MONITORAMENTO DA UMIDADE DO SOLO POR MEIO DA PLATAFORMA ARDUINO

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1 RESUMO

O monitoramento da umidade do solo é de suma importância para o manejo de sistemas irrigados, promovendo o uso eficiente de água na. Assim, o trabalho teve como objetivo calibrar e avaliar sensores de umidade do solo utilizando a plataforma Arduino. O trabalho foi desenvolvido no laboratório da Universidade Federal Rural da Amazônia (UFRA). As amostras de solo foram obtidas no território do Campus Tomé-Açu, em vegetação de mata secundária, sendo o solo classificado como Latossolo Vermelho-Amarelo. Foram utilizados três sensores modelo (YL-69) e seis sensores de umidade do solo anticorrosivos (S-12), os quais foram instalados em vasos de polietileno contendo aproximadamente 1,0 dm^3 de solo. Os sensores foram conectados a um sistema de aquisição de dados composto por um microcontrolador Arduino® UNO. Os sensores YL-69 apresentaram um bom ajuste ao modelo de regressão linear (R2>0,90). Por sua vez, os sensores S-12 (anticorrosivo) obtiveram melhor ajuste ao modelo matemático de potência, com coeficientes de determinação na faixa de 0,8312 a 0,8554. Os sensores YL-69 e S-12 apresentaram ajustes satisfatórios para a curva de calibração acima do coeficiente de determinação de 0,83.

Keywords: Monitoramento, Irrigação, Automação e Instrumentação Agrícola.

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CALIBRATION AND EVALUATION OF SOIL MOISTURE SENSORS FOR SOIL MOISTURE MONITORING USING THE ARDUINO PLATFORM

2 ABSTRACT

Monitoring soil moisture is highly important for the management of irrigated systems and promotes the efficient use of water. Thus, this study aimed to calibrate and evaluate soil moisture sensors using the Arduino platform. The work was carried out in the laboratory of the Federal Rural University of the Amazon (UFRA). Soil samples were obtained from the Tomé-Açu Campus territory in secondary forest vegetation, with the soil classified as red–yellow latosol. Three (YL-69) model sensors and six anti-corrosive soil moisture sensors (S-12) were used, which were installed in polyethylene pots containing approximately 1.0 dm³ of soil. The sensors were connected to a data acquisition system consisting of an Arduino® UNO microcontroller. The YL-69 sensors fit the linear regression model well (R^2>0.90). In turn, the S-12 (anti-corrosive) sensors achieved a better fit to the power mathematical model, with coefficients of determination in the range of 0.8312 to 0.8554. Both the YL-69 and S-12 sensors showed satisfactory fits for the calibration curve above the coefficient of determination of 0.83.

Keywords: Monitoring, Irrigation, Agricultural Automation and Instrumentation.

3 INTRODUCTION

Knowledge of the water available in the soil profile is highly relevant for agricultural activities and is indispensable for crop development. This is because the frequency of irrigation depends on the amount of water stored in the soil (Buske). *et al.*, 2013).

Modern agriculture is increasingly dependent on digital tools and automation to maximize the productivity of water applied per unit of agricultural product obtained, and in this sense, several technologies have been proposed to monitor soil moisture through digital platforms.

The modern context of the development of digitization processes in production systems, within the context of the Internet of Things, associated with the "Maker Movement", has popularized the application of embedded systems with Arduino for various applications (agricultural, residential, industrial, etc.) (Barbon *et al.*, 2016; Azevedo *et al.*, 2024). The development of artificial intelligence, coupled with the increasing accumulation of data in agriculture, has enabled more detailed analyses of processes and their optimization (Gao *et al.*, 2025). One of the important factors in the correct application of these technologies is knowledge of the behavior of the sensors used in data collection, involving factors that influence activities, such as sensors for climatic parameters, soil moisture, monitoring the operation of agricultural machinery, etc.

With respect to soil sensors, the diversity of models and operating principles demands technical criteria for their selection, such as applicability in the environment, accuracy in data collection in various soil types, durability, cost, and ease of handling and installation. It is necessary to state that, among these factors, calibration is a factor that must be taken into account for any model chosen since for each sensor installed, even for the same model, there may be variations in the sensor response curve in relation to soil moisture (Todd *et al.*, 2025). Therefore, the objective of this work was to calibrate and evaluate the YL-69 and S12 soil moisture sensors connected to an Arduino platform.

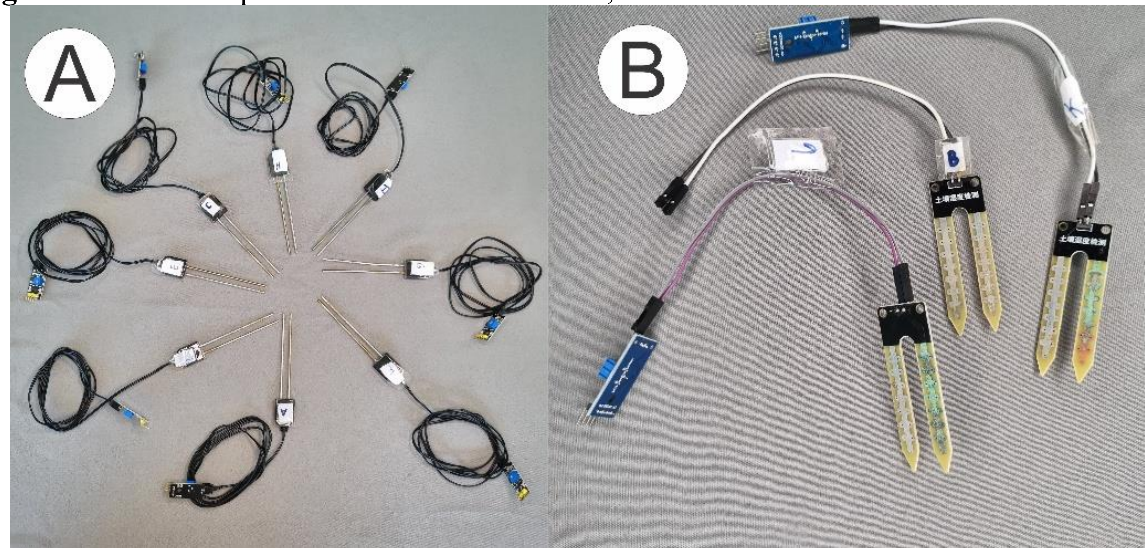
4 MATERIALS AND METHODS

The soil moisture sensor calibration experiment was conducted at the Water and Soil Engineering Laboratory of the Federal Rural University of the Amazon, Tomé-Açu Campus, Pará, located at a latitude of -2°40'449.63”, a longitude of -48°16'429.56” and an altitude of 19 m.

To determine the composition of the pots, soil was collected at a depth of 0.20 m from under secondary forest vegetation on the Tomé-Açu Campus. The soil of the area is classified as a dystrophic Red–Yellow Latosol (Brazil; Cravo; Viegas, 2020). To subsequently remove debris such as branches, leaves, and roots, the material was sieved through 2.5 mm sieves. After this process, the samples were taken to the laboratory and placed in nine pots, with a height of 80.7 mm, a lower diameter of 96.7 mm, and an upper diameter of 127.2 mm. After this preparation, the samples were saturated with water for 24 hours and subsequently air dried before being subjected to laboratory tests.

Six corrosion-resistant soil moisture sensors and three YL-69 model sensors were used, which were installed in #14 polyethylene pots containing soil. The sensors were connected to a data acquisition system composed of an Arduino® UNO microcontroller, operated by programming a code in C++, edited in the Arduino IDE® platform’ in the Arduino development environment for collecting analog data from the sensors (IDE) (Table 1). The sensors are shown in Figures 1A and 1B.

Figure 1. A: S-12 capacitive soil moisture sensor; B: YL-69 soil moisture sensor.



Source: The authors.

Table 1. Code used in data collection.

```
#define pinSensorA A0//identifies the analog inputs of each sensor
#define pinSensorB A2
#define pinSensorC A4
#define pinSensorD A5

void setup (){
  Serial.begin (9600);//Initializes the Serial Monitor
}
void loop(){
  Serial.print ("Value A = ");//Prints text to the Serial Monitor
  Serial.print (analogRead (pinSensorA));
  Serial.print ("; ");
  Serial.print ("Value B = ");
  Serial.print (analogRead (pinSensorB));
  Serial.print ("; ");
  Serial.print ("Value C = ");
  Serial.print (analogRead (pinSensorC));
  Serial.print ("; ");
  Serial.print ("Value D = ");
  Serial.print (analogRead (pinSensorD));
  Serial.println ("; ");
  delay(1000);
}
```

Source: The authors

Data collection was performed using an Arduino® microcontroller $^{\text{powered}}$ directly by the computer via a 5 V USB port. The information was updated every second on the serial monitor of the Arduino programming environment. A precision balance with two decimal places of accuracy was used to weigh the analyzed samples. Initially, initial weightings were performed, both with and without the moisture sensors, to obtain the weight of the soil only at the analyzed moisture point.

This procedure was conducted as a preliminary step before periodic weighting was initiated. To collect data from the humidity sensors on the Arduino platform, a 5-minute period was used to allow the readings to stabilize before data collection began. These data were subsequently recorded and stored in a spreadsheet.

After data collection was completed, the soil samples were subjected to drying in an oven at 105°C for a period of 72 hours (Teixeira *et al.,* 2017) to determine the final water content present in the soil samples and the dry mass of the soil in each pot.

On the basis of the gravimetric data and dry soil values, gravimetric moisture was estimated using Equation 1, which was corrected using soil density to obtain volumetric moisture with the application of Equation 2.

$$CGA = \frac{(a-b)}{b} \tag{1}$$

where:

CGA – gravimetric water content (moisture on a gravimetric basis), in gg^{-1}.

a – Mass of the wet sample, in g.

b – Mass of the sample dried at 105°C until it reaches a constant weight, in g.

$$CVA = \rho * \frac{(a-b)}{c} \text{or} CVA = \rho * CGA * Ds \quad (2)$$

where:

CVA – Volumetric water content (moisture on a volumetric basis), in m^3 m^{-3}.

ρ– specific gravity of water at 4.0°C, in g cm^{-3};

CGA – gravimetric water content (moisture on a gravimetric basis), in kg kg^{-1}.

a – Mass of the wet sample, in g.

b – Mass of the sample dried at 105°C until it reaches a constant weight, in g.

c – Sample volume, in cm^3.

Ds is the soil density in g cm^{-3} (equivalent to kg dm^{-3}).

Soil density was determined using the undisturbed sample method recommended by EMBRAPA (Teixeira *et al.,* 2017), which is described in Equation 3.

$$Ds = \frac{Mss}{V} \quad (3)$$

In what way:

Ds – soil density calculated considering the undisturbed sample, in g cm^{-3}.

mss – mass of dry soil, even when disturbed or compacted, after centrifugation (mass of the sample plus the mass of the volumetric cylinder, after drying in an oven at 105°C until constant weight is reached, minus the mass of the empty, clean and dry ring), in g.

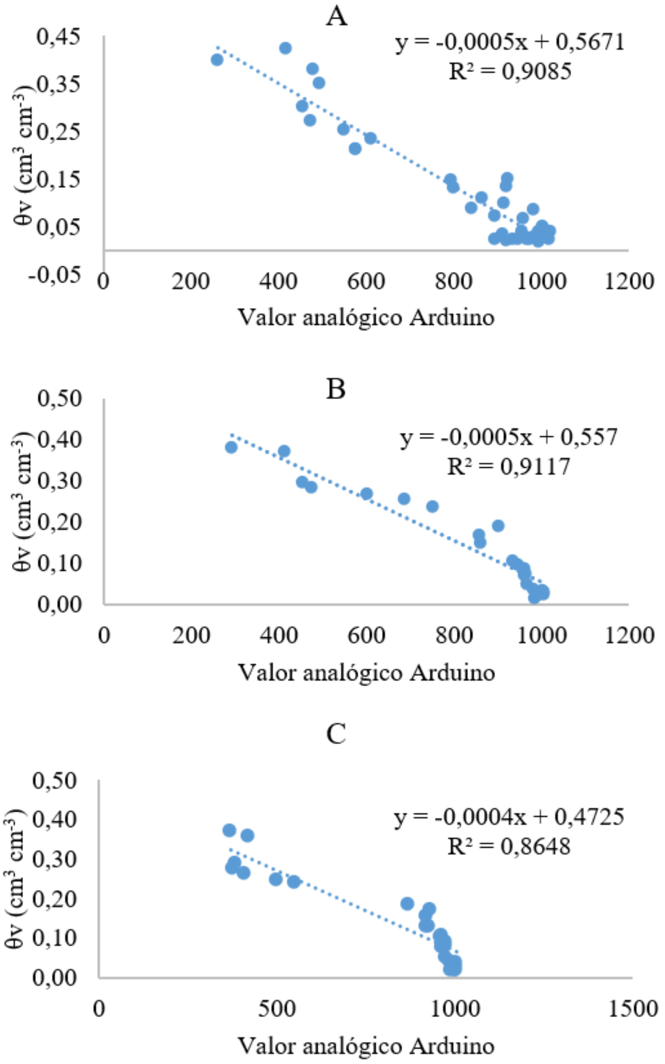
V – volume of the cylinder, which corresponds to the original volume of the undeformed sample, in cm^3.

The data were subjected to different mathematical models to select the calibration curve for each sensor that obtained the best fit, considering the coefficient of determination, with the aid of the Excel platform.

5 RESULTS AND DISCUSSION

The YL-69 sensors showed a decreasing fit to the linear regression model. The coefficients of determination (R^2) ranged from 0.8648 to 0.9085, indicating a good fit, as shown in Figure 2. These R^2 values are considered “very good” according to Moriasi’s classification criteria. *et al.* . (2015).

Figure 2. Calibration curves of the YL-69 sensors of specimens A (A), B (B) and C (C).



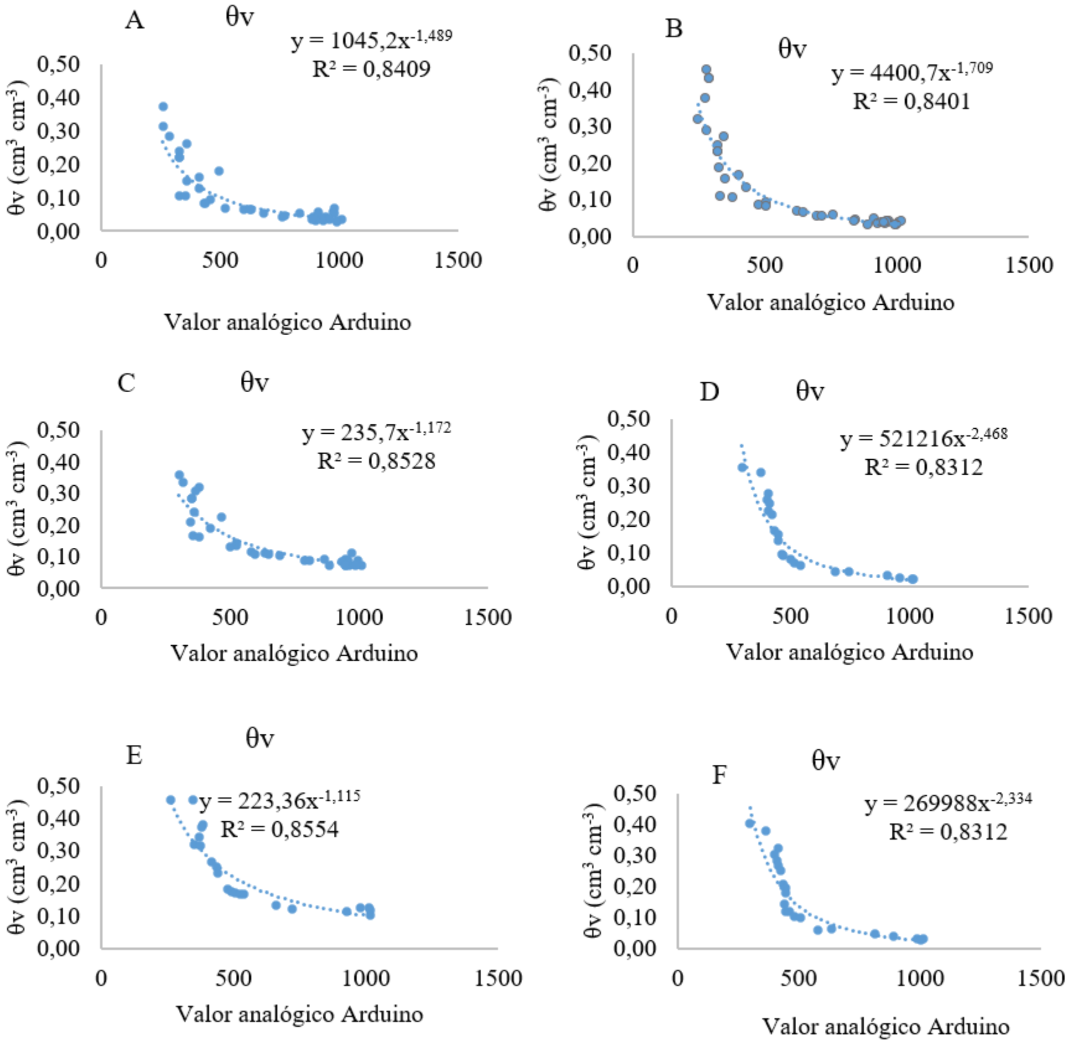
Source: The authors.

Jiménez (2018) worked with the calibration of the YL-69 sensor for four soil classes and reported that for each soil type, the calibration curves fit different models, namely, linear and quadratic regression and an exponential model, indicating that a specific calibration is necessary for each soil type. In this work, it was also observed that the calibration curves had “very good” fits (R2 > 0.85).

In turn, the S-12 (anti-corrosion) sensors obtained a more appropriate fit to the potential mathematical model, with coefficients of determination in the range of 0.8312 to 0.8554, which is classified as “good” according to Moriasi’s classification. *et al.* . (2015).

In this adjustment, it is observed that at the beginning of the model curve, there is a greater reduction in moisture values, while there is a slight increase in the analog values obtained by the sensors; on the other hand, from the middle of the curve onward, the decrease in moisture is smaller, and the analog values increase at a rate. Under these conditions, the sensors are more sensitive to soils with lower water contents. The graphs in Figure 3 show the adjustments for the S-12 models.

Figure 3. Calibration curves of the S-12 sensors of specimens A (A), B (B), C (C), D (D), E (E) and F (F).

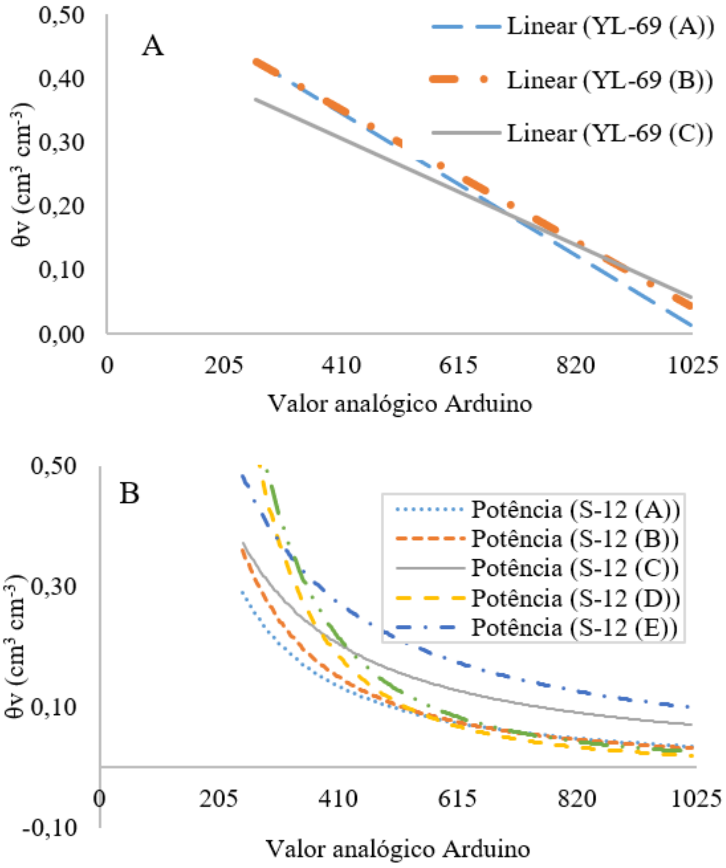


Source: The authors.

Silva *et al.* (2018) evaluated the performance of different soil moisture sensors (one of each type) in four soil classes. In this study, the sensors that used some of the dielectric properties of the soil fit the linear regression model well. The authors reported that low-cost models (XH300 and PM100) are not recommended for use in scientific research and concluded that specific calibrations are necessary for each soil classification.

The YL-69 sensors shown in Figure 4A fit the linear regression model well; however, the sensors obtained slightly discrepant calibration curves among the sensors of the same model. The calibration curve of specimen YL-69 (C) is farther from the others when the soil is wetter, whereas the curve of specimen YL-69 (A) is farther from the others when the soil is drier (Figure 4A).

Figure 3. Comparison between the adjustments of the YL-69 (A) and S-12 (B) sensor models.



Source: The authors.

For the S-12 model samples, a greater discrepancy was observed between the calibration curves. As shown in Figure 4B, a greater difference is noted between the curves of specimens (A) and (E). For both calibrated models (YL-69 and S-12), specific calibrations are required for each sample. This individual behavior of soil sensors was observed by (Balthazar *et al.,* 2025), who analyzed the capacity of moisture sensors to monitor the water content in chicken litter and reported that calibration is necessary individually for sensors of the same model.

6 CONCLUSION

The YL-69 and S-12 sensors showed satisfactory adjustments for the calibration curve above the coefficient of determination of 0.83. For each sample, for the same model used on the Arduino platform, specific calibration is necessary. The YL-69 model presented a “very good” calibration rating, indicating better calibration performance.

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