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Stability of soil moisture sensors for agricultural crop cultivation

Sitti Nur Faridah[1*], *Muhammad Tahir Sapsal*[1], *Tisha Aditya A. Jamaluddin*[2], *Andini Dani Achmad*[3], *Muhammad Adi Surya*[1]

[1]*Agricultural Technology Department, Faculty of Agriculture, Hasanuddin University, Makassar, Indonesia*
[2]*Energy Conversion and Conservation Research Center, National Research and Innovation Agency, South Tangerang Banten, Indonesia*
[3]*Electrical Engineering Department, Faculty of Engineering, Hasanuddin University, Gowa, Indonesia*

**Corresponding author: faridah_sn@agri.unhas.ac.id*

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Abstract: Soil water content is critical in plants' morphological and physiological processes; therefore, water must always be available in appropriate quantities to meet plant growth needs. Soil moisture can be easily detected using sensors, which offer a practical solution for monitoring water content in the soil. However, using sensors for a long time, especially on agricultural land, will reduce sensor accuracy. This research aims to investigate the accuracy of soil moisture sensors during their use for cultivating crops. Using sensors in sandy clay soil can detect soil moisture levels with an accuracy of 93.80% and a precision of 90.81%. A reading deviation (error) of up to 49.74% with a precision level of 75.69% occurred when the sensor had been used for 40 days. Regular cleaning and calibration of the sensor are necessary to obtain accurate soil moisture readings. A copper-based sensor module kit can be used to detect soil moisture with reasonable accuracy during plant growth with a 5–6 weeks harvest time.

Keywords: agricultural land; copper sensor; sandy clay; soil water content

Soil is an ideal plant-growing medium (Marcos & Muzaki 2022). Most of the water and nutrients required by plants are absorbed from the soil. The soil provides nutrients and mechanical support for plants, which is influenced by the water content in the soil (Purba et al. 2021). Soil water is important for plants, especially to fulfil transpiration in the process of assimilating the formation of carbohydrates and carrying the results of photosynthesis throughout plant tissues (Chaves et al. 2002; Hammer et al. 2021). Soil water dissolves nutrients in the soil, carries nutrients to the surface of plant roots, and transports nutrients throughout plant tissue (Bhatnagar et al. 2019). According to Shao et al. (2008), a water deficit is the dominant factor inhibiting plant growth compared to other environmental factors. A water deficit in plants will inhibit metabolic processes, causing plants to become stunted and their development to be disrupted (Osakabe et al. 2014). According to Faridah et al. (2023) and Marjenah (2010), soil water content influences the morphological and physiological processes of plants; therefore, water must always be available in quantities appropriate to the needs of plant growth (Shock et al. 2002; Qin et al. 2021; Yu et al. 2021).

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Soil moisture is a critical parameter for managing agricultural production. For smart agricultural land irrigation, accurate and real-time soil moisture measurements must be conducted. Agricultural plants are usually 5–13 weeks old, especially food crops. To accurately detect soil moisture in plants, sensors can be used (Ganjegunte et al. 2012; Faridah et al. 2014; Lutfiyana et al. 2017; Yu et al. 2021). The sensor is very easy to use and does not require special maintenance. Changes in the volume of water in the soil, or soil moisture, can be observed through changes in the soil's ability to conduct electricity. The higher the volume of water in the soil, the higher the soil's ability to conduct electricity (Shevnin et al. 2007; Bhatt & Jain 2014; Hariri et al. 2019). Changes in voltage can be detected with a soil moisture sensor; this sensor consists of two probes that pass current through the soil, read resistance fluctuations in the soil, and send this information to the microcontroller in the form of voltage. The voltage information is then converted into soil moisture data (Lailhacar & Dukes 2010; Jumasa & Saputro 2019; Suparman et al. 2023)

The long-term use of sensors, particularly in the agricultural sector, can reduce sensor accuracy due to the influence of various environmental factors. (Lailhacar & Dukes 2010; Ganjegunte et al. 2012; Sui 2018; Kanso et al. 2020). Sensor calibration is essential to ensure accurate soil moisture detection in sandy clay soil. According to Hermawan (2005) and Candra et al. (2015), the ability of soil to absorb water depends on the type of soil; therefore, the use of sensor equipment needs to be calibrated because the level of sensor validity is related to soil characteristics (Shock et al. 2016; Brahma et al. 2017; Kanso et al. 2020). However, studies regarding the stability of soil moisture sensors are still very limited. This research investigates the accuracy of soil moisture sensors made from copper for cultivating crops.

MATERIAL AND METHODS

The Soil Moisture Sensor is a module designed to detect soil moisture, which can be accessed using microcontrollers such as Arduino or ESP32, enabling monitoring of soil moisture levels around plants offline and online. This research uses a soil moisture sensor made from copper with type HD 38 sensor specifications in Table 1.

Table 1. Specifications of soil moisture sensors

No.	Unit	Specification
1.	Voltage	DC 3.3–12 V
2.	Current	20 mA (output current 30 mA)
3.	Module dimensions	36 × 15 × 7 mm
4.	Probe length	8.8 cm
5.	Cable length	2.2 m
6.	Sensor connecting port	XH2.54 2P
7.	Supported	Arduino, ESP8266, STM32, raspberry, relay module

The HD 38 sensor module operates at a DC voltage of 3.3–12 V and has four pins, two for the power supply and two for different output modes (analogue and digital). When using the Digital Output Pin, the output will only be 1 or 0, with the conversion process done by reading the digital value using the command digitalRead (pin number). On the other hand, if using the Analog Output Pin, the output is a voltage value. If connected to an Arduino module, the display will show the converted voltage value to ADC, ranging from 0 to 1 023 (10-bit ADC mode) or 0 to 253 (8-bit ADC mode), with the reading done using the command analogRead (pin number). The soil moisture sensor system circuit is shown in Figure 1.

Statistical analysis. Calibration of the sensor using linear regression analysis involves comparing the voltage readings, which have been converted through the ADC (analogue-to-digital converter) feature on the Arduino module, with the moisture content measurements obtained through the gravimetric method. The electrical voltage that flows through the ground is proportional to the change in soil moisture.

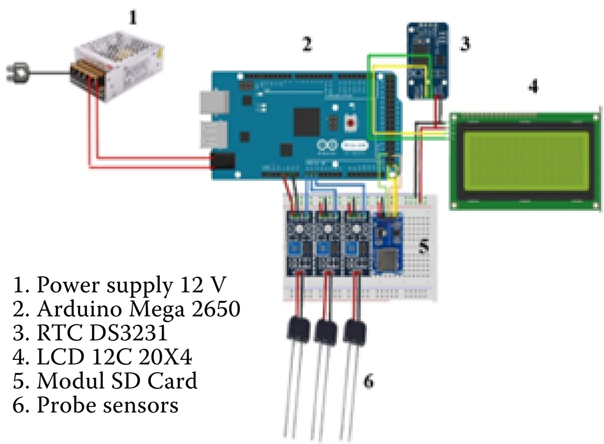

Figure 1. Series of soil moisture sensors systems

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Moisture measurements were conducted in sandy clay soil using three sensors, with six repetitions for each measurement time. The accuracy of the sensor system was validated by comparing the sensor readings with the gravimetric method, with tests conducted on days 1, 40, and 80. Accuracy analysis was conducted using an equation (Gao et al. 2018; Cahyono et al. 2019):

$$\text{Accuracy} = 100\% - \text{error } (\%) \tag{1}$$

$$\text{Error} = \left[\frac{\text{sensor value} - \text{standard measurement value}}{\text{standard measurement value}}\right] \times 100 \tag{2}$$

The level of sensor precision is analyzed using standard deviation with the equation (Bentley 2005):

$$\text{Precision} = 100\% - \text{Standard deviation } (\%) \tag{3}$$

RESULTS AND DISCUSSION

The calibration results show that the sensor output voltage decreases as the water content in the soil increases (Figure 2). In line with research conducted by Parashar and Parashar (2021), Schwamback et al. (2023), and Zhang et al. (2018), the sensor output voltage and soil water content are a linear function of negative correlation.

Figure 2 shows the linear relationship between soil moisture and voltage on the sensor, with an average R^2 value of 0.9272. The R^2 value is closer to 1, the more linear the comparison between soil moisture and voltage on the sensor, which indicates a better level of validation. According to Sulistyani et al. (2021) and Sir et al. (2016), sensor calibration with a linearity test is crucial for evaluating the method's validity; the more linear the regression line, the higher the validation level.

Soil moisture readings from the sensor on the first day ranged from 5.39 to 29.75%, while the gravimetric method showed values between 4.77 and 28.61%. The sensor error below 6.5% was found in 4 water volumetric treatments (66.67%) and two treatments above 10%. The average soil moisture from the sensor was 18.05% and gravimetric 17.18%, with an error of 6.20% (Figure 3).

Table 2. Characteristics of the kit module type soil moisture sensor

No.	Day	Sensors	Precision (%)	Accuracy (%)
1	1	1	91.03	94.68
		2	90.74	96.16
		3	90.70	90.55
2	40	1	76.22	50.06
		2	76.05	51.66
		3	74.80	49.06
3	80	1	64.57	29.91
		2	62.91	31.39
		3	63.57	30.82

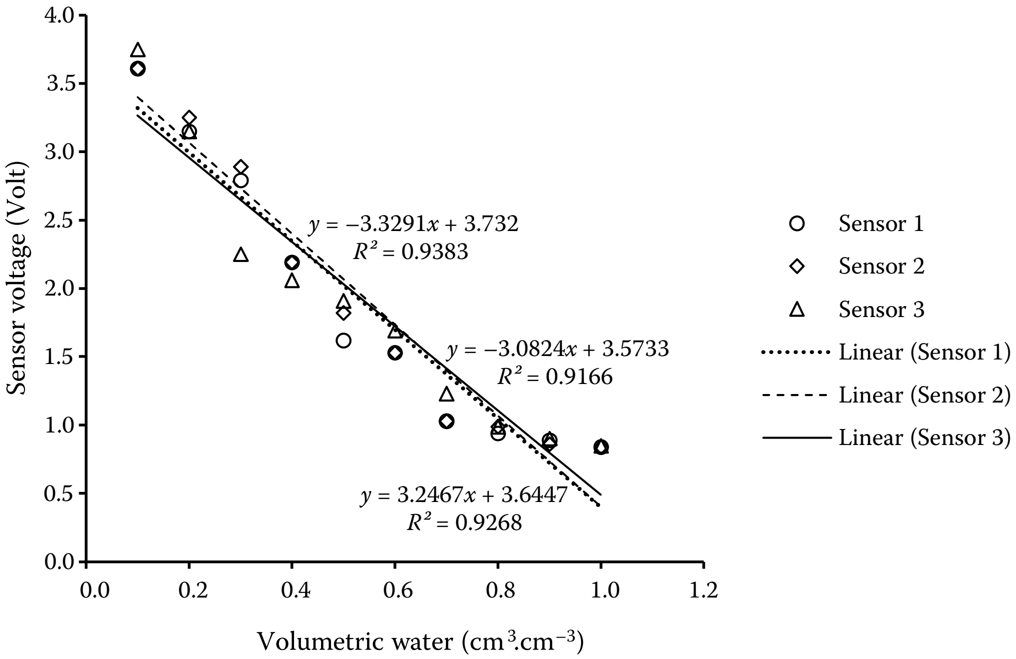

Figure 2. Sensor calibration

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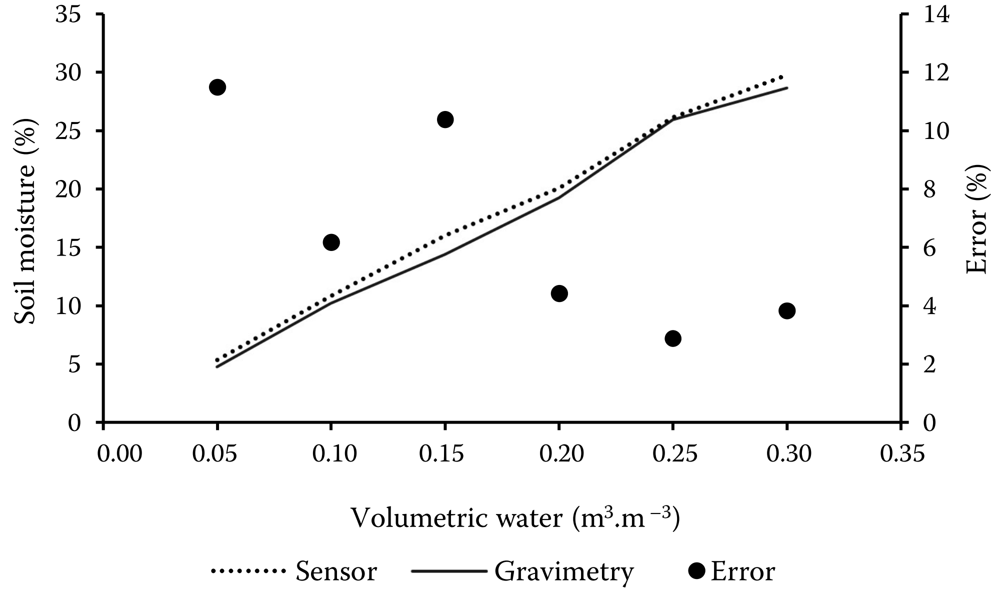

Figure 3. Relationship between soil moisture using the gravimetric method and sensor readings day 1

The sensor accurately detects soil moisture levels on day 1 of sensor use. The value of soil moisture from the sensor readings is close to that of the gravimetric method, with an accuracy of 93.80% (Table 2). The precision value is 90.81%, which shows that the sensor has quite high precision and on repeated measurements, the sensor produces a stable reading level for each measurement. The precision value shows high reading consistency with an average error of less than 6.5%. According to the statement of Cahyono et al. (2019) and Yudha and Sani (2017), precision measurements show the closeness of the value of each measurement on the sensor.

Sensor readings on day 40 exhibited an error of 49.74% and a precision of 75.69%. The sensor remained relatively accurate (89.38%) in detecting soil moisture levels below 10% (Figure 4). However, when the soil moisture exceeded 10%, the sensor accuracy dropped between 49.06 and 51.66% (Table 2). This decrease in accuracy was found with increased water volumetric, which is allegedly confounding the sensor readings. According to Lailhacar and Dukes (2010) and Taber et al. (2002), wet soil conditions, resulting from more frequent irrigation, contribute to higher sensor error. After 40 days of use, the sensor's accuracy decreased by 56.82%. To maintain ad-

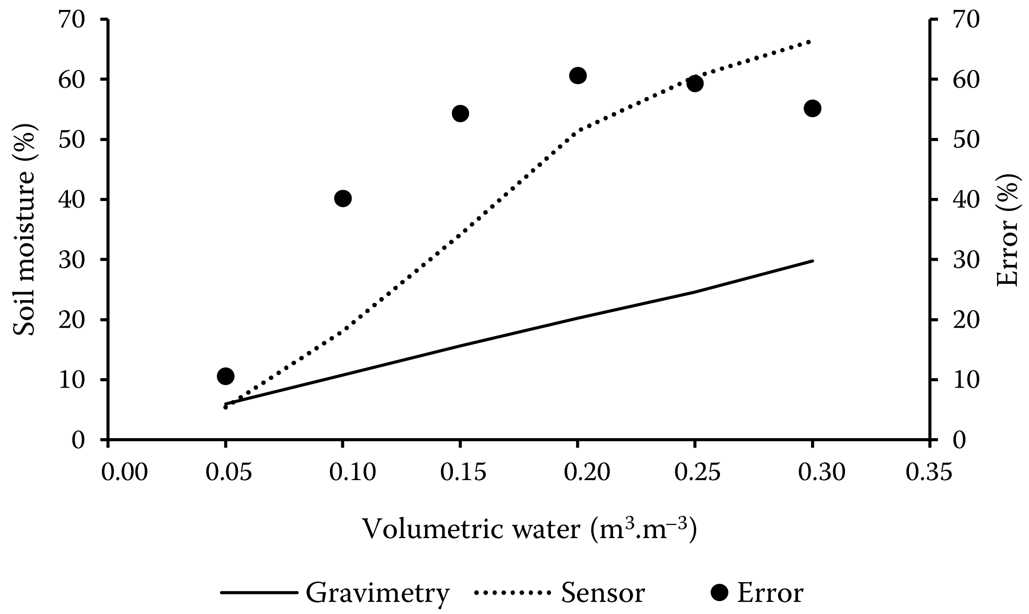

Figure 4. Relationship between soil moisture using the gravimetric method and sensor readings day 40

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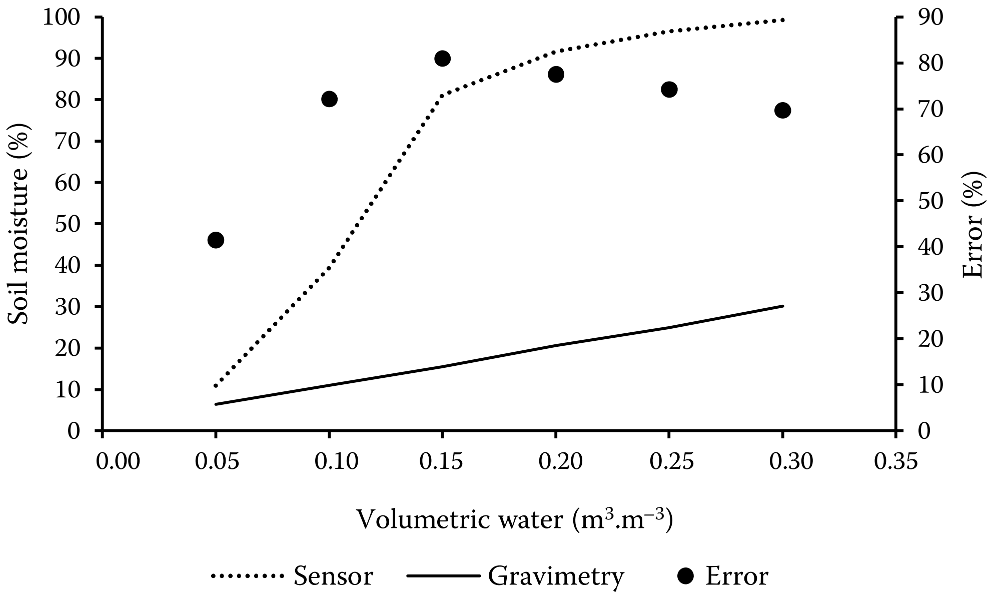

Figure 5. Relationship between soil moisture using the gravimetric method and sensor readings day 80

equate accuracy, it is essential to regularly clean and calibrate the soil moisture sensor. According to the statement by Hatanaka et al. (2015), Rosma et al. (2021), and Salman et al. (2021), to increase the accuracy of soil moisture sensors, a sensor calibration process is needed. According to Yudo (2018), cleanliness maintenance and sensor calibration are carried out routinely and periodically to anticipate data errors. The sensor must be calibrated for accurate and stable results (Gao et al. 2018; Qinglan et al. 2020).

On day 80, the soil moisture readings from the sensor ranged from 10.89 to 99.25%, while the gravimetric method indicated a range of 6.37 to 30.08%, with an error of 69.29% (Figure 5). Corrosion was found on several parts of the sensor probe; on the 80th day of use, the sensor was no longer accurate at 30.71% (Table 2). It is used for a long time, causing corrosion on the sensor probe. It is used for a long time, causing corrosion on the sensor probe. According to the research results of Songara and Patel (2022), most copper sensors will corrode within 2 months. Copper sensors can only detect soil moisture accurately enough for seasonal crops with a harvest age of about 40 days. In line with research by Hermawan (2005), using soil moisture sensors from copper can remain in the soil for 30–35 days.

CONCLUSION

Using a soil moisture sensor on sandy clay soil demonstrated an accuracy of 93.80% and a precision of 90.81%. After approximately 40 days of use, the accuracy decreased by 56.82%. Maintaining cleanliness and regularly calibrating copper sensors can detect soil moisture quite accurately during plant growth with a 5–6 weeks harvest age. With advancements in data analytics and artificial intelligence, sensors can provide more in-depth analysis and more accurate predictions regarding irrigation needs, drought potential, and the impact of climate change on soil moisture.

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