Assessment of the TEROS 10 and TEROS 12 sensors in soil moisture measurement

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Abstract. This study focuses on investigating the accuracy of the empirical equations proposed by the manufacturing company for the widely used TEROS 10 and TEROS 12 sensors. Specifically, the study examines whether the raw - unprocessed - measurements provided by the two sensors lead to reliable predictions of soil moisture and electrical conductivity values when these particular empirical equations are utilized. For this purpose, a prototype setup was developed, incorporating a low-cost microcontroller along with auxiliary power supply and data acquisition circuits for the sensors. The results highlight the need for specific calibration of the sensors for each soil type and salinity level. Additionally, the behaviour of the sensors operating at low frequency (70 MHz) under increasing salinity conditions is contrary to expectations.

1 Introduction

The reliable estimation of soil moisture values in fields and crops constitutes an important tool for proper irrigation scheduling both temporally and spatially. Moreover, it can significantly contribute to water conservation by preventing over-irrigation and promoting the sustainability of natural resources [1, 2]. The scientific processing of real-time data collected by devices like capacitance sensors enables the elimination or substantial mitigation of risks that threaten or negatively affect the course of cultivation [3, 4]. The farmer can have a comprehensive view at every point of their land, accurately determine irrigation timing and required water quantity, intervention time, as well as the type and amount of pest control and fertilization to apply [5]. The integrated online management of agricultural operations entails making informed decisions to optimize production both qualitatively and quantitatively given that the most precise measurements possible lead to the most accurate decision-making [6].

The aim of this study is to verify and investigate the accuracy of the proposed equations for predicting the moisture content (θ) as well as the dielectric permittivity (ε_a) in specific soil types under increasing moisture conditions. The method, which includes the measurement of soil properties such as moisture, temperature and dielectric permittivity [7,

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8], is implemented in a well-defined way under laboratory conditions, using the latest generation TEROS 10 and TEROS 12 sensors [9-10] manufactured by Metergroup.

Following the Introduction, the remainder of this paper is structured as follows. In section 2 the experimental testbed is being overviewed and the methods for performing the required measurements are described. In section 3 the results deriving by the conducted measurements are being presented and discussed. The paper concludes in section 4 where some interesting outcomes are being deducted.

2 Materials and Methods

2.1 Experimental testbed

2.1.1 The TEROS 10 sensor

The TEROS 10 sensor can estimate the volumetric water content in soil using an industrial calibration equation. It emits an electromagnetic wave with a frequency of 70 MHz, which minimizes interferences due to soil salinity or texture. The raw values outputted by the sensor for the measured parameters are unprocessed and are converted into values of soil moisture content (θ) and dielectric permittivity using the following industrial calibration equations where (1) represents the equation for the moisture content whereas (2) the one for the dielectric permittivity.

$$\Theta(m^3/m^3) = 4.824\times10^{-10}\times mV^3 - 2.278\times10^{-6}\times mV^2 + 3.898\times10^{-3}\times mV - 2.154\ ; \quad (1)$$

$$\varepsilon = 1.054\times10^{-1}\times e^{\,2.827\times10-3\ \times mV.} \quad (2)$$

2.1.2 The TEROS 12 sensor

The Teros 12 sensor, which represents the upgraded digital version of the TEROS 10, indirectly calculates the volumetric water content in soil by computing the apparent electrical permittivity (ε_a) of the porous medium. Additionally, it records the apparent electrical conductivity (σ_b) and temperature by emitting an electromagnetic wave with a frequency of 70 MHz. It features three stainless steel rods instead of the two present in the Teros 10 sensor and is compatible with most data logging systems.

The calibration equations derived from the raw unprocessed values are provided by the following relationships, where (3) represents the equation for moisture content and (4) for dielectric permittivity.

$$\Theta(m^3/m^3) = 3.879\times10^{-4}\times RAW - 0.6956\ ; \quad (3)$$

$$\varepsilon = (2.887\times10^{-9}\times RAW^3 - 2.080\times10^{-5}\times RAW^2 + 5.276\times10^{-2}\times RAW - 43.39)^2. \quad (4)$$

2.1.3 The implementation circuit

The prototype implementation circuit, as depicted in Figure 1 consists of an Arduino-type microcontroller, a multiplexer, a voltage converter, sensor sockets, a battery, and a USB cable for computer connection. Specifically, a low-power consumption Arduino-type microcontroller board was used, with input pins for digital and analogue signals and output pins at 3.3 V. Additionally, it has an integrated chip for communication via the USB protocol and is compatible with the Arduino IDE development environment. The voltage converter raised the voltage from 3.3 to 5 volts, and the multiplexer directed the data to the desired input line.

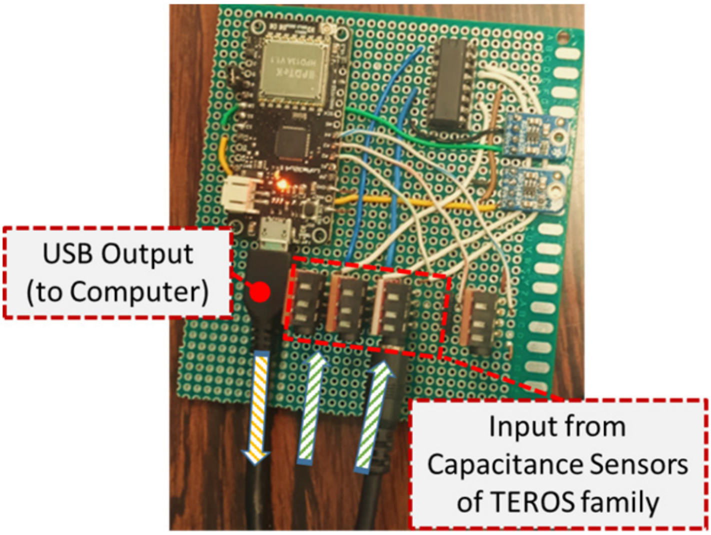

Fig. 1. Prototype implementation circuit.

2.2 Measurements in disturbed soils

Samples of soils (such as sandy soil and sandy loam) were utilized, in which moisture increase was strictly controlled until field capacity was reached. Specifically, for each soil type, a soil sample of 1500 ml volume was used, to which water was added in increments of 75 ml each time to increase the moisture content by $\theta=0.05$. Great emphasis was placed on maintaining the initial volume of the soil sample each time moisture increase occurred, as well as ensuring uniform water distribution within the sample. After drying in an oven for 24 hours, the soil samples were sieved through a 2 mm sieve. For each moisture and electrical conductivity (EC) value, four measurements were recorded for each sensor separately to avoid potential errors, and then the mean value was calculated. In addition to measurements with water with EC=0.28 dS/m, a similar experiment was conducted with solutions with EC= 2.92, 6.2, and 10 dS/m to investigate the effect of EC on dielectric permittivity values at each soil moisture level.

2.3 Measurements on aqueous solutions with increased salinity

In addition, in a specific volume of water, we gradually increased salinity from 0 to approximately 20 dS/m by adding potassium chloride (KCl), recording the salinity (EC_w) each time using a conductivity meter. With the sensors, we measured any variations in electrical conductivity to determine if the value remained stable (80) or changed with the increase in EC_w of the solution. This experiment serves as a guide for assessing the effect of EC_w of the solution on the stability of dielectric permittivity measurements. The manufacturing company claims that the value of dielectric permittivity is not affected until EC = 8 dS/m.

3 Results and Discussion

Measurements indicated that the dielectric permittivity changes with the increase in EC and does not remain constant up to 8 dS/m as stated in the manufacturer's manual. According to the dielectric permittivity-EC diagram for TEROS 12, as depicted in Figure 2, it is evident that the dielectric permittivity initially decreases to approximately 60 with the increase in EC up to around 2 dS/m and then gradually increases. At high EC values, it reaches values close to 80. The TEROS 10 exhibits a similar behaviour, with the dielectric permittivity decreasing to around 50 and then increasing, converging after stabilization to a value of about 75 dS/m. The values of ε_a recorded by TEROS 10 are generally somewhat lower than those of TEROS 12 for each salinity level.

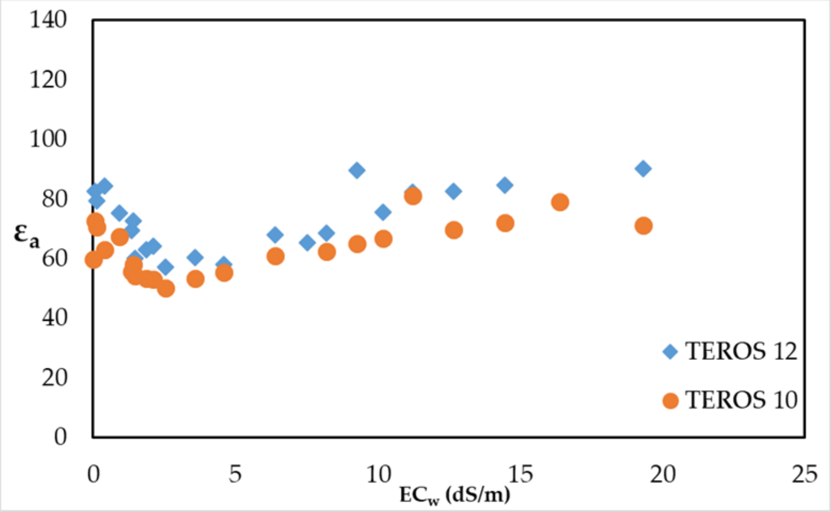

Fig. 2. Electrical permittivity - salinity diagram for measurements with Teros 10 & 12 in aqueous solution.

According to Figure 3 and Figure 4, it is evident that the relationship between θ and permittivity is influenced by the EC value of the soil solution. Specifically, at each θ value, the permittivity value is lower as the EC value of the soil solution increases. This unexpected behavior of the two sensors is likely attributed to their construction. This fact indicates that the manufacturer's calibration equation cannot be applied in cases of increasing soil salinity. Therefore, there is a need for specific calibration of the devices in each case if the goal is accurate estimation of soil moisture.

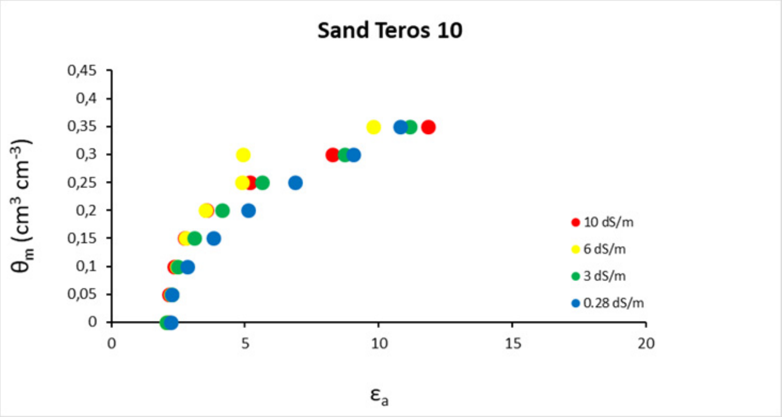

Fig. 3. Moisture - Electrical permittivity diagram for measurements with TEROS 10 in sandy soil.

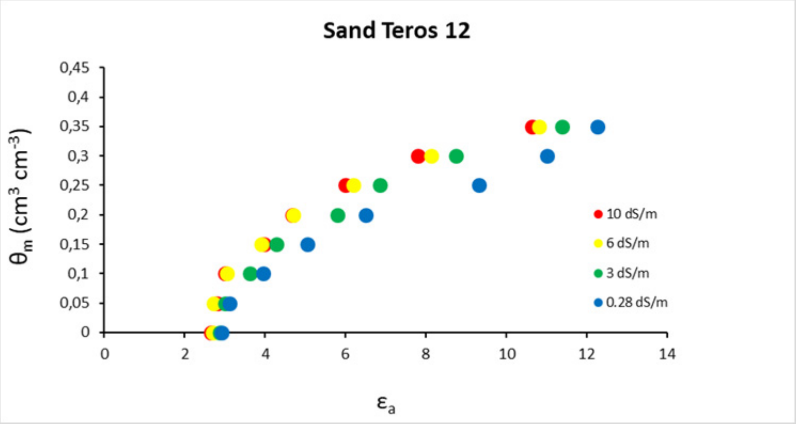

Fig. 4. Moisture - Electrical permittivity diagram for measurements with TEROS 12 in sandy soil.

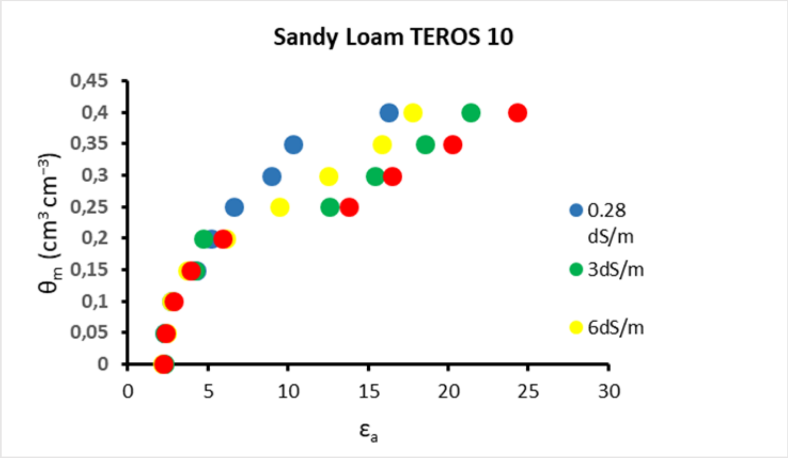

Fig. 5. Moisture - Electrical permittivity diagram for measurements with TEROS 10 in sandy loam.

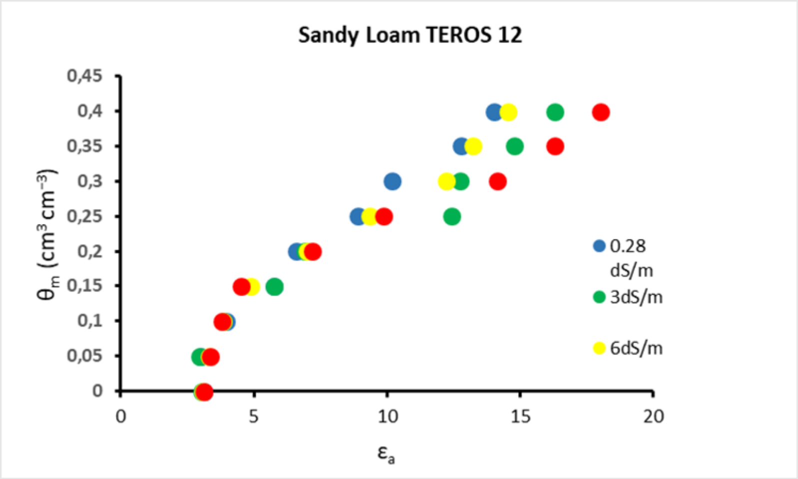

Fig. 6. Moisture - Electrical permittivity diagram for measurements with TEROS 12 in sandy loam.

This paradoxical phenomenon is also observed in other soils, such as in loam with Teros 10, where the ε_a values are higher for EC=0.28 than for EC=3 or 6 dS/m at the same moisture level as depicted in Figure 5 and Figure 6. The fact that while the salinity (EC) increases, the apparent dielectric permittivity (ε_a) decreases (instead of increasing) at the same moisture level (θ) is particularly pronounced in sandy soil and sandy loam and is considered to be a significant finding.

4 Conclusion

The objective of this research was to validate and examine the precision of the suggested formulas for forecasting both the moisture content (θ) and the dielectric permittivity (ε_a) in designated soil types experiencing escalating moisture levels. The methodology, involving the assessment of soil attributes like moisture, temperature, and dielectric permittivity, was systematically executed in a laboratory setting, employing the TEROS 10 and TEROS 12 sensors. As measurements indicated, achieving accurate prediction of θ requires specific calibration of the devices for each soil type and salinity level. It is inferred that the electrical permittivity for both sensors does not remain constant with increasing salinity up to 8 dS/m, and that the relationship between θ and conductivity is influenced by the EC value of the soil solution, especially at higher levels. This behaviour is related to their response to s_b, which is highly nonlinear and inversely directed, shifting from negative at low s_b values to positive at high s_b values.

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