Low Cost and Simple Soil Moisture Measurement Using Multi-Level Capacitive Technique

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Abstract

Global warming and climate change can cause water scarcity and drought for agricultural areas. Automatic irrigation can be one of the possible solutions for optimum water usage but has to cooperate with soil moisture measurement. However, the devices for soil moisture measurement at present are relatively expansive and require high technical setup and test skills; especially, for multi-depth soil moisture measurement. This paper proposes an alternatively low cost, simple soil moisture profile measurement using the multi-level capacitive technique. The proposed measurement technique was developed and tested by observing the moisture and water absorption capacity of sand, loam and clay soils at a depth up to 30 cm from the ground surface. It is found that the proposed measuring prototype could clearly classify levels of water infiltration, distribution and storage for particular different levels of the soil samples (The uncertainty values: RMSE from soils sandy, loam and clay by less than 8.50, 10.72, and 16.19 VMC%). The results also showed feasibility of the technique that could be used to study behavior of plants and crops in order to achieve the optimum water and moisture supply profile for different types of their roots in particular different soil depths for the best growth rate or quality.

Keywords: Automatic irrigation, Moisture measurement system, Precise farming, Simple real-time IoT-based, Soil water infiltration

I. INTRODUCTION

Agricultural industry is one of the most essential parts for country development for many countries, including Thailand [1]. Agricultural industry and agro-product export play an important role for the development of Thailand [2]–[4]. It is generally known that water is the important factor for agricultural cultivation, but problems related to water shortage and drought are still existing in Thailand because of global warming and climate change [5], [6]. It makes a water shortage for farmers to cultivate. When dehydrated plants result in the quality and productivity of agriculture will decline, the product is more expensive affecting the domestic economy. Precise farming with automatic irrigation technology could be used for optimum water usage for crops and saving water [7]–[9]. It also helps the plants to grow properly and get quality agricultural productivity [10].

To install the automatic irrigation system, soil moisture measurement devices with capability of real-time monitoring and multi-depth soil moisture profile measurement are needed [10], [11]. Unfortunately, these devices that are currently available in marketplace inherently have high prices, which would be difficult for the local farmers to effort.

II. LITERATURE REVIEW

A. Importance of Soil Moisture and Measurement Techniques

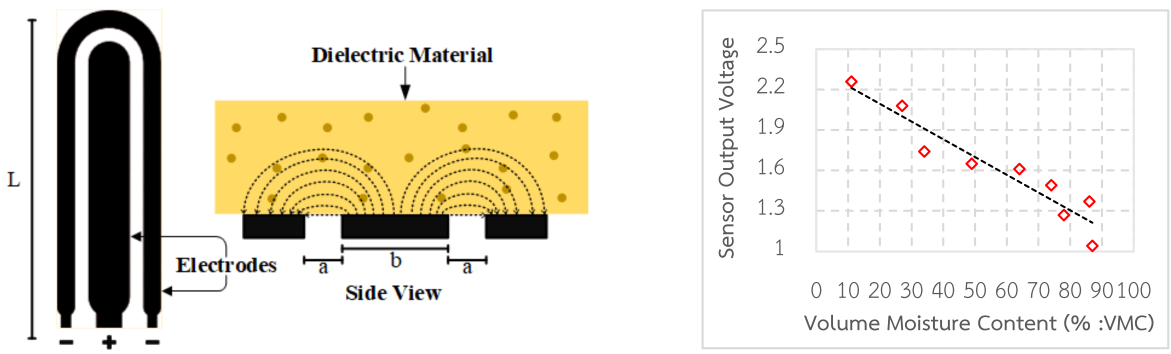
Soil moisture is the water that is in the gaps of soil. Soil moisture plays an important role for crops and plants, as well as, chemical, biological and physical of soil. This presents indirect soil moisture measurement using mainly the electrical-conductivity techniques [12], which are the well-known and commonly used technique for precise farming worldwide [13]. Measuring soil moisture to determine automatic irrigation not only helps farmers conserve water resources for their cultivation, but it also helps to achieve higher quality yields by controlling the soil moisture according to plant needs. In addition, maintaining optimum soil moisture and structure will increase the soil's water retention capacity, which is an important part of preventing and managing flood risks [14]. Estimation of transpiration (ET) and soil moisture (SMC) It is important in food security research, water resource management, wildfire detection etc. [15].

Soil moisture measurement can be by direct method or indirect method. The direct methods such the gravimetric water content, but this method would take long testing time, destroy the soil, and not be possible for real-time monitoring. The indirect methods could be one of the following methods: heat-plus, remote sensing, hygrometric, EMI, capacitive, resistive [16]. Alternatively, Soil moisture measurement could be also divided by the output signals, which are Time Domain Reflectometry (TDR), Frequency Domain (FD), Reflectometry and Capacitance, Time Domain Transmission (TDT), Amplitude Domain Reflectometry (ADR) and Phase Transmission sensor [17].

From the literature review on the estimation methods of soil moisture and their operation time could be summarized that the direct measurement method such as gravimetric water content has high accuracy, low cost, but destroy soil and take long time. On the other hands, the indirect measurement method such Time Domain Reflectometry (TDR) and Ground Penetrating Radar (GPR) would be suitable for large area but could not be the cost-effective method and difficult for the forests compared to TDR method [18]. The criteria for the selection of the indirect soil measurement types are dependent on the types of soil and method to calibrate the measuring tools.

B. Capacitive Soil Moisture Sensor Theory

Capacitive soil moisture sensor has low price and plenty in the Thailand marketplaces.



(a) (b)

Figure 1: Capacitive soil moisture sensor probe V1.2 (a) structure [20]; (b) Percent moisture-voltage characteristic curves of the probe

These probes utilize the change of dielectric value when indirect contact with different amounts of moisture (water). In this way, the proposed device using capacitive technique offers advantages over the resistive technique as it prevents rusting. [19]; having a simple structure as shown in Figure 1 These probe types are rough, robust, precise and allowable for providing analogue output signal with voltage range between 3.3–5.0 V and thus easy to operate with a microcontroller.

C. Design and Development of a Multi-Level Soil Moisture Measurement

It is suggested in [20] that to measure soil moisture, the probe should be placed about 15 cm from the ground surface, and it would be better to use the multi-depth soil moisture measurement since different types of crops would require different amount of water for their roots. The research results of [21] showed that the traditional resistive probe would have some problem when contacting soil for a long time due to the corrosions; especially, when using in the deep soil ground. The research results in [22] also supported that the capacitive probe with 12 serial peripheral interfaces had higher efficiency and less cost than a single serial interface. In [23], the capacitive with the wireless data sensing based the Zigbee configuration for their designed fringing electric field probe could effectively measure the soil moisture in the range of 1-80% but would work well only near surface soil ground measurement. The researchers [24] also developed a fast response, precise real-time soil moisture measurement using IoT with time multiplexing technique, which claimed that they achieved low cost and high accuracy measurement with the error less than 1.35%. Similarly, the capacitive based IoT module (SKU: SEN0193) was developed by [25], which provided creditable data, as well as, helped for precise moisture control for the investigated greenhouse. The research proposed in [26] employed solar power for a large, measured data storage system as the additional system for soil moisture tests, which helped for water prediction and management.

However, there are some concerns regarding the use of capacitive probes as follows. The research results in [27] suggested that preparation of soil in terms of cavity of soil affected the creditable measured results of soil moisture.

III. RESEARCH METHODOLOGY

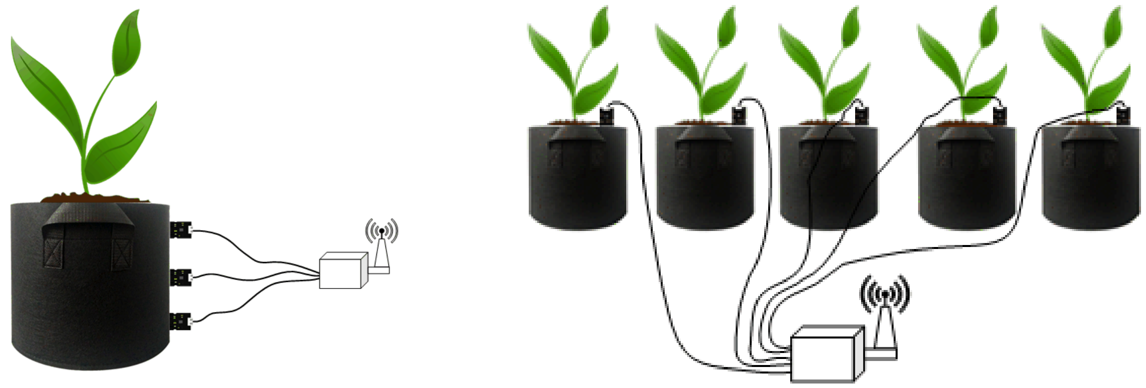
In this research, we utilized low-cost and simple capacitive moisture sensors V1.2 in conjunction with a microcontroller board. The microcontroller board not only facilitated recording, analysis, and display of the measured data but also incorporated real-time functionality through an IoT application.

A. Design System and Construction of Prototype

The data Centre for agricultural information [28] Thailand uses over 238,803 square kilometers of agricultural land, which accounts for 46% of the total area of the country. Therefore, we have designed a simple, inexpensive soil moisture meter to replace expensive equipment with complex applications as well as causing widespread use among local farmers to take advantage of the soil moisture measurements. Figure 2a shows the design concept of the multi-level capacitive soil moisture measurement under this research. Simple commercial capacitive soil moisture sensors are inserted into the target soil levels. The measured data will be then sent to microcontroller board and then transmitted via the wireless module to the end receivers (users). For greenhouses, several sets of measuring devices could also possibly be set up as shown in Figure 2b, and display screen (Looker studio of Google App) are shown in Figure 5 and 6.

We have applied Probe capacitive soil moisture sensor V.1.2 combined with module Wi-Fi (Table 1) which such equipment can be purchased in the country It is economical and farmers can search for how to use it from the Internet widely. The operation flowchart of

the proposed device is shown in Figure 3, Electrical equipment connections are shown in Figure 4, while the transmitted data on the Google sheet (receiver) and the display screen (Looker studio of Google App) are shown in Figure 5 and Figure 6, respectively.



(a) (b)

Figure 2: Design concept: (a) field implementation; (b) possible multi-measurement

Table 1: The total cost of the developed low-cost and simple capacitive soil moisture multi-level system

Component	Applied for	Units	Cost (฿)	Subtotal (฿)
Capacitive Soil Moisture Sensor v1.2	Measure soil moisture.	5	50	250
ESP32 (DevKitC-32UE)	Process soil moisture values and send data to Google Sheet.	1	350	350
Other components	Equipment for system and infiltration tests in laboratory	1	1,500	1,500
Total (THB in 2023)				2,100

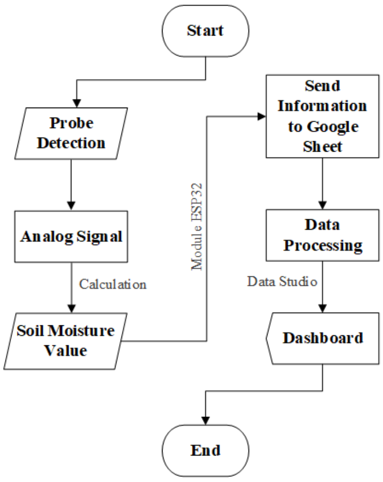


Figure 3: Operation flowchart of the proposed soil moisture measurement device in this research

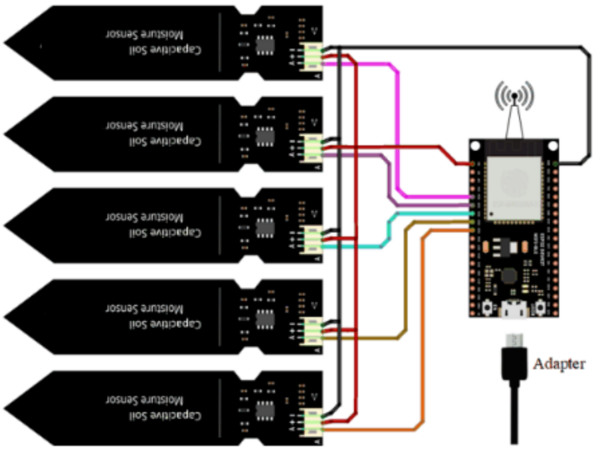
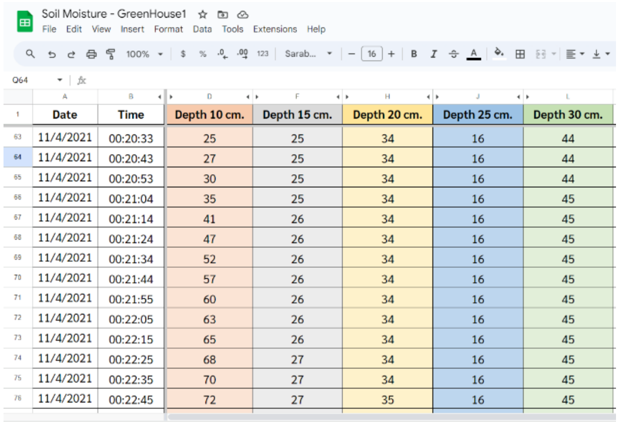


Figure 4: Device electrical wiring diagram in this research



Date	Time	Depth 10 cm.	Depth 15 cm.	Depth 20 cm.	Depth 25 cm.	Depth 30 cm.
11/4/2021	00:20:33	25	25	34	16	44
11/4/2021	00:20:43	27	25	34	16	44
11/4/2021	00:20:53	30	25	34	16	44
11/4/2021	00:21:04	35	25	34	16	45
11/4/2021	00:21:14	41	26	34	16	45
11/4/2021	00:21:24	47	26	34	16	45
11/4/2021	00:21:34	52	26	34	16	45
11/4/2021	00:21:44	57	26	34	16	45
11/4/2021	00:21:55	60	26	34	16	45
11/4/2021	00:22:05	63	26	34	16	45
11/4/2021	00:22:15	65	26	34	16	45
11/4/2021	00:22:25	68	27	34	16	45
11/4/2021	00:22:35	70	27	34	16	45
11/4/2021	00:22:45	72	27	35	16	45

Figure 5: Example of transmitted data in the Google sheet receive

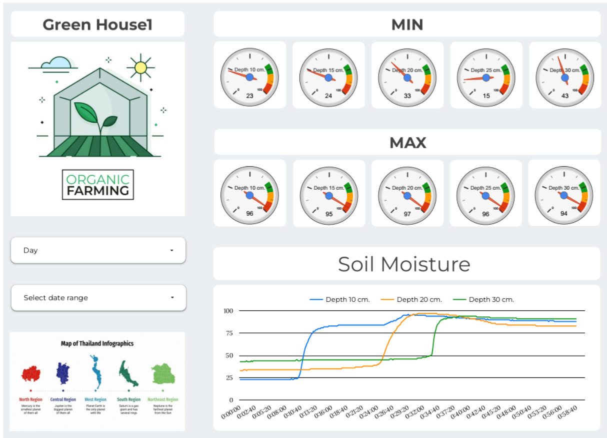
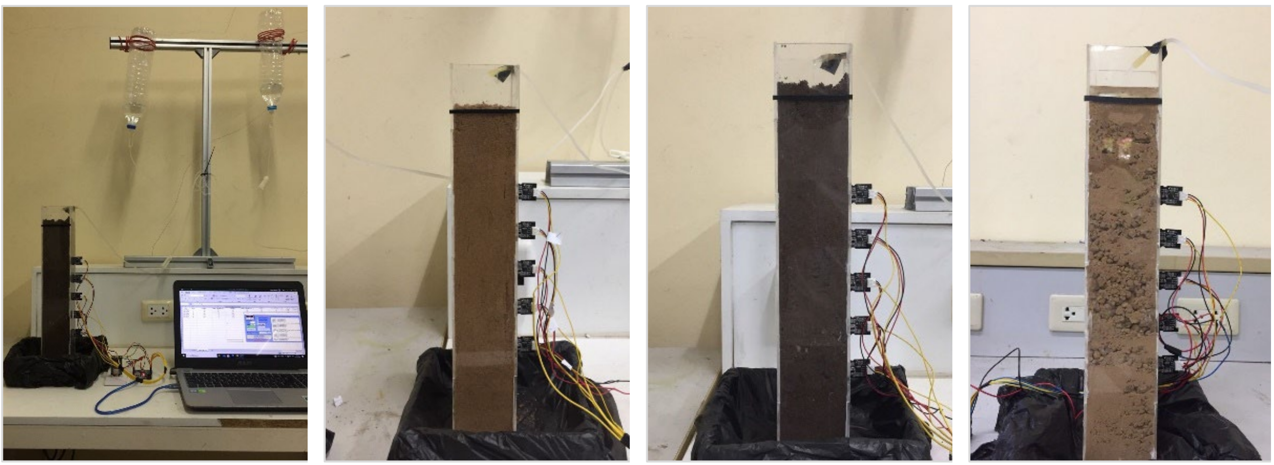


Figure 6: Display screen of the transmitted data collection



(a) (b) (c) (d)

Figure 7: (a) Infiltration testing the proposed multi-level soil moisture measurement; (b) sandy soil; (c) loam soil; (d) clay soil

IV. RESULTS AND DISCUSSION

Figure 8–10 show the experimental test results obtained from the tests for sandy soil, loam soil and clay soil when placing the capacitive sensor at the depth of 10–30 cm with different amounts of supplying water of 150, 250, and 350 ml for 60 minutes. Regarding soil theory, it is generally known that the investigated soil types have the properties as shown in Table 2 [29].

Table 2: Approximate ranges in soil particle, water and nutrient holding capacities for soils of differing textures [29]

Soil Texture	Soil Particle Diameter (mm)	Available Water Holding Capacity (in/ft)
Sand or loamy sand	0.050 - 2.000	< 0.6
Sandy loam		0.6-1.0
Loam or silt loam	0.002 - 0.050	1.0-1.5
Clay loam		1.5-2.0
Clay	< 0.002	> 2.0

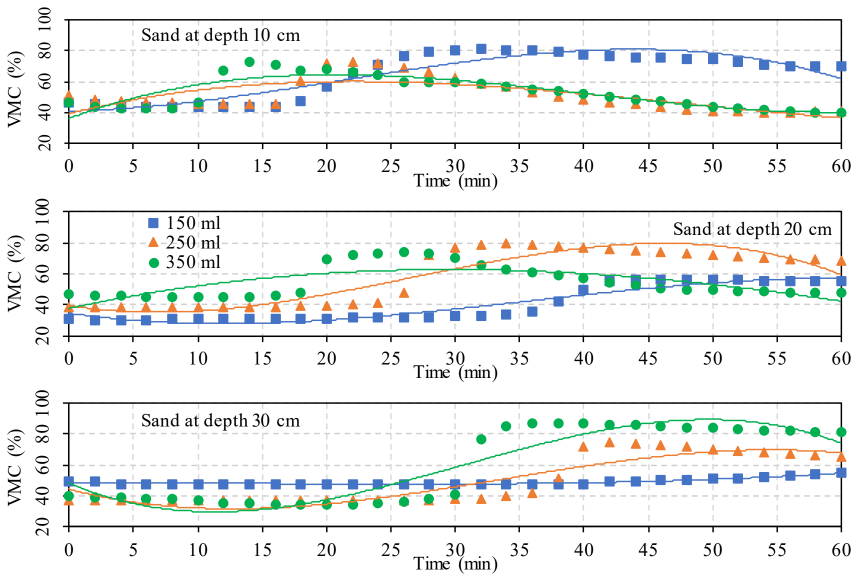


Figure 8. Test results and analysis of moisture values of sandy soil in different irrigation

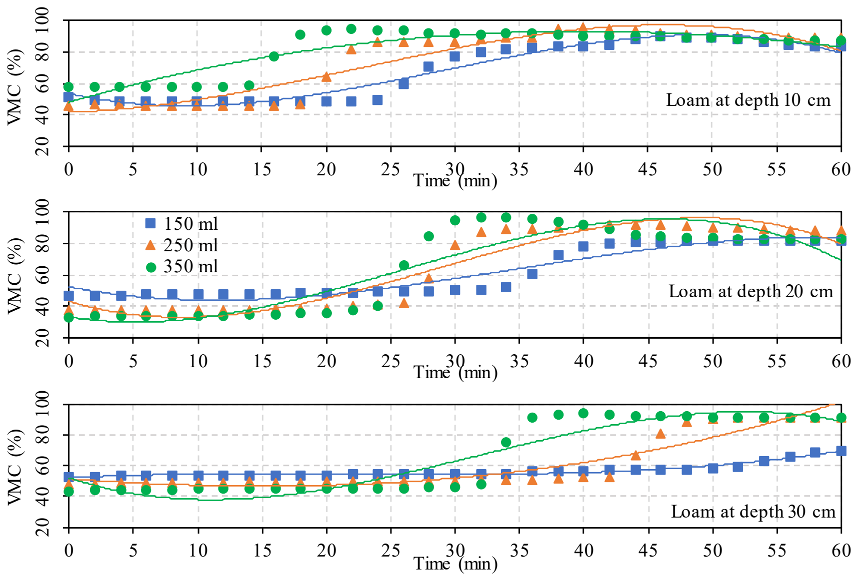


Figure 9. Test results and analysis of moisture values of loam soil in different irrigations

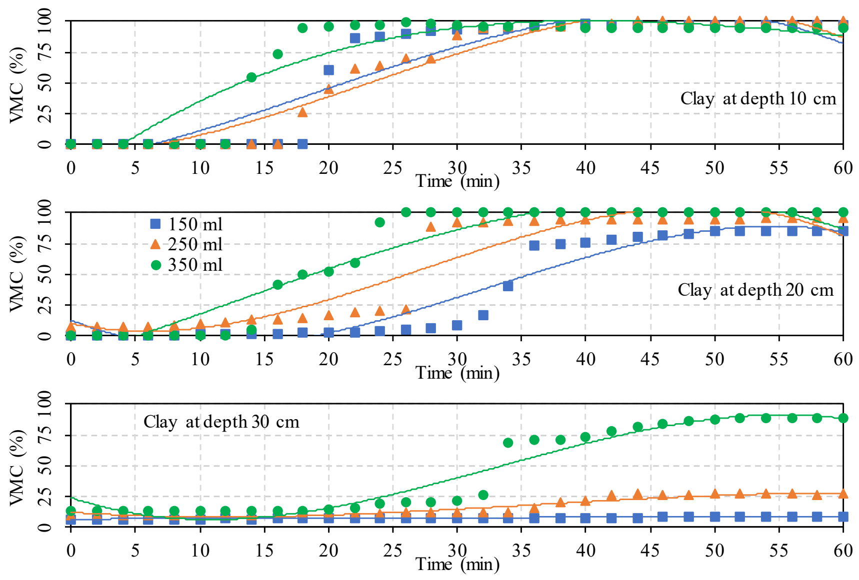


Figure 10. Test results and analysis of moisture values of clay soil in different irrigation

It can be seen from the test results that:

1) The proposed multi-depth soil moisture measurement device could be used to predict the behavior of the water absorption in different soil types correctly. For example, in Figure 8, for small amount of supply water of 150 ml, the top sensors could be measuring the moisture but the bottom sensors could not due to there was no water available to get down to the bottom. In turn, when the amount of water increased, the bottom sensors started to have some moisture appeared. Similar results would be found for the tests with the loam soil and clay soil in Figure 9 and Figure 10, respectively.

2) The proposed soil moisture measurement device could be used to predict the absorption rate of the soil in terms of the water and nutrient holding as shown in Table 2. It can be seen in Figure 8 that the sandy soil has low capacity of water holding capacity, which could be noticed from the rapid decrease of the tailing edge of the graphs. On the other hands, the loam soil and clay soil would hold the amount of water well, which could be noticed from the nearly stable tailing edge of the graphs for both sample loam and clay soils as shown in Figure 9 and Figure 10.

3) The different of the graphs could be seen among the tests even with the same amount of water supplying and testing time (see Figure 8, 9 and 10). This reveals that the absorbing path of the water through the same soil type could be totally different. Therefore, only few moisture soil profiles would not be precisely predicting the water behavior of the soil, in fact, several measured profiles could be used for the more precise and accurate soil moisture profile measurement.

4) For field applied, sensor circuits need to be protected from environmental conditions (e.g., resin molding) for longer sensor life, including the use of signal interference-proof cables (e.g., Fuel Shield). In addition, Wi-Fi has a small coverage. In practice, the node might be too far from the Wi-Fi.

Table 3: Parameters of prediction of water absorption behavior of different types of soils and uncertainty of measuring systems

Soil	Depth	Water content	$y = ax^3 + bx^2 + cx + d$				R^2	RMSE
			a	b	c	d		
Sand	10 cm	150 ml	-0.0009	0.0559	0.1455	41.005	0.86	5.79
		250 ml	0.0004	-0.0617	2.0956	39.227	0.54	7.56
		350 ml	0.0008	-0.1014	3.1068	36.182	0.77	6.21
	20 cm	150 ml	-0.0005	0.0588	-1.1802	34.493	0.90	5.33
		250 ml	-0.0014	0.1153	-1.3642	39.523	0.85	7.91
		350 ml	0.0001	-0.0349	1.7842	37.719	0.52	6.91
	30 cm	150 ml	9.00E-05	-0.0036	0.0036	48.507	0.97	0.31
		250 ml	-0.001	0.1044	-2.145	44.273	0.82	7.10
		350 ml	-0.0021	0.1931	-3.5496	48.267	0.87	8.50
Loam	10 cm	150 ml	-0.0014	0.1216	-1.8585	53.797	0.95	3.90
		250 ml	-0.001	0.0691	0.1942	41.946	0.89	6.94
		350 ml	7.00E-05	-0.0343	2.3783	48.159	0.80	6.38
	20 cm	150 ml	-0.0008	0.0819	-1.5754	52.524	0.91	4.77
		250 ml	-0.0019	0.1664	-2.4529	43.223	0.92	7.20
		350 ml	-0.0019	0.144	-1.3278	33.441	0.84	10.72
	30 cm	150 ml	0.0003	-0.0203	0.4089	52.185	0.95	1.04
		250 ml	0.0001	0.0165	-0.5792	51.374	0.88	6.02
		350 ml	-0.0016	0.1516	-2.7567	52.121	0.87	7.99
Clay	10 cm	150 ml	-0.0016	0.0915	1.7876	-14.109	0.86	16.19
		250 ml	-0.0019	0.1307	0.5094	-8.5757	0.94	10.10
		350 ml	0.0008	-0.1427	7.649	-27.913	0.85	15.13
	20 cm	150 ml	-0.0023	0.2288	-4.1569	12.832	0.92	10.52
		250 ml	-0.0025	0.2079	-2.1762	10.147	0.89	13.30
		350 ml	-0.0011	0.0376	3.271	-17.464	0.91	13.24
	30 cm	150 ml	2.00E-05	-0.0016	0.0719	6.8064	0.83	0.32
		250 ml	-0.0003	0.0366	-0.7063	12.338	0.92	4.07
		350 ml	-0.0019	0.192	-3.4855	24.162	0.93	8.73

To achieve high resolution of curve fitting, the 3rd order polynomial function was utilized for the measured results, which revealed that for sandy soils, the prediction coefficient ranged from 0.52 to 0.97, with an uncertainty range of 0.31 to 8.50 VMC%. Notably, the minimum and maximum values were obtained from the sensor at a depth of 30 cm. For loamy soils, the results showed that the prediction coefficient ranged from 0.80 to 0.95, with the highest values observed at sensors 10 and 30 cm. The corresponding uncertainty ranged from 3.90 to 10.72 VMC%. Based on the test results, it can be concluded that sandy and loam soils exhibit increasing uncertainty values as the amount of irrigation increases. In the case of clay soils, the results indicated that the prediction coefficient ranged from 0.83 to 0.94. However, most uncertainty values exceeded ±10 VMC% (ranging from 0.32 to 16.19), This is due to the density and gaps between soils, resulting in the observed variability.

It could be summarized from the results of the analysis according to table 3 that the proposed multi-depth soil mois-ture measurement using multi-level capacitive technique under this research could be used to predict the behavior of the soil water movement of different soil types among sandy soil, loam soil and clay soil. In contrast, unknown soil samples can also be tested and printed using the proposed soil moisture measurement technique as well. This multi-depth soil profile can be used for further studies to reduce uncertainty. This includes determining the appropriate or proper amount of water necessary for proper growth or optimal quality of agricultural products, and so on.

V. CONCLUSIONS

This paper proposes the new low-cost device to measure soil moisture for the multi-depth soil using multi-level capacitive moisture sensors V.1.2. The proposed device could be used to observe behavior of water absorption and water hold in the different types of soil and, in turn, could be used to test and identify the type of the soil sample. There were 3 types of soils used to examine and evaluate the proposed device in this research, which were the sandy soil, the loam soil and the clay soil. The test results showed that the proposed device could be able to produce the correct soil moisture profile, could be used to observe the capacity of water holding for the soil, proof that the water absorption by the same soil type can be totally different, and eventually, used to identify the type of the soil sample. These results facilitate the comprehension of the uncertainty associated with soil moisture measurement for each soil type. Consequently, it is advisable to perform calibration in areas requiring measurements to optimize efficiency.

This multi-depth soil profile could then be used for the further study on the suitable or optimum amount of water that would be required for the best growth or the best quality of the agricultural products and so on. This is also to achieve the best utilization of the water for the cultivation during the shortage of water or during the drought season.

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