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Sensitivity of PR2 Capacitance Soil Moisture Meter for Irrigation Scheduling

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Abstract*: Accurate soil moisture content measurement is essential for designing a robust irrigation scheduling and integrated water resources management (I.W.R.M.). Capacitance-based sensors have widely been used to monitor soil moisture at different measuring depths coupled with continuous and instantaneous outputs. This study's objective was to evaluate the PR2 capacitance moisture meter's performance on mineral and organic soil water content. The outputs of PR2 in m^3/m^3 and vol.% were compared with gravimetrically measured soil moisture. The R.M.S.E. measurement at Site A at the first and second replicates increased from 0.49% to 0.67%. In contrast, the r^2 value of 0.99 was obtained for the two replications when comparing the soil moisture content observed from gravimetric measurement and the automated outputs from the PR2 Probe soil monitor. The R.M.S.E. values were 0.48%, and 1.32% were estimated for the first and second replications at Site B. The result indicates that the PR2 Profile Probe could be a reliable alternative to other time-consuming, complex computer algorithms for accurate point measurement of soil moisture.

***Keywords*: PR2 Probe, Soil moisture, Mineral soil, Organic soil, Capacitance sensor, Permittivity.**

I. INTRODUCTION

Accurate measurement of soil moisture content is crucial for designing a robust irrigation scheduling and a significant hydrological variable component. Smart and integrated agricultural practices require adequate understanding and knowledge of soil moisture depletion and rises. [1] showed that soil moisture is essential in agronomic, hydrological, and meteorological processes. Accurate estimation of soil moisture can also be applied for creating sustainable integrated water resource management (IWRM) and develop a geotechnical matrix. Thus understand the behavior of foundational soil under cycles of drying and wetting periods. The seasonal effects of moisture content related to subbase are essential to determine the nature and technique useful to develop hydraulic structures. Also, sensitive data on soil moisture can be useful as an indicator for predicting natural disasters, such as drought and flooding, and for environmental change, such as dust storms and erosion [1]. Changes in soil moisture depend mostly on hydraulic conductivity, while other factors such as soil structure, texture, and soil types are essential for measuring soil moisture. [2] showed that hydraulic properties are indispensable for addressing many soil types, hydrological, environmental, ecological, and agricultural problems. Estimation of soil moisture content could be categorized into direct and indirect approaches. The direct method is a point measurement that includes a thermo-gravimetric method, tensiometer, PR2/6 capacitance moisture meter, neutron probe, and others. However, the indirect method uses an empirically-based relationship of water balance components to estimate soil moisture. Accuracy, precision, and variability are concepts that are important to obtaining valid values [3]. Findings have indicated that the gravimetric method estimates soil moisture with high accuracy and precision, but the process is slow and time-consuming. Other point measurements of soil moisture meters such as neutron probe, domain reflectometry, tensiometer, and PR2 capacitance moisture monitor can estimate soil moisture changes in both organic and mineral soils.

Soil moisture sensors, or soil volumetric water content sensors, displayed soil moisture content in a percentage output. There is a possibility that the value is a product of derivation from the generic soil layer of the soil moisture sensor origin. The electromagnetic-based sensors belong to situ soil moisture measuring approaches, producing immediate and continuous at a high spatial and temporal resolution [4]. It is necessary to calibrate and validate any soil moisture monitor to set an acceptable limit of accuracy. Several researchers calibrate a particular model of soil moisture for each different type of soil or substrate. In contrast, others calibrate every single soil moisture for each type of soil [5]. Calibration is essential when a soil moisture sensor is applied to determine the magnitude of plant water use, soil moisture deficit, and estimate soil water balance [5]. Several researchers have focused on the calibration and normalization of electromagnetic-based sensors applied in different sensing techniques [6].

This study presents the Probe Profile 2 capacitance moisture sensor calibration for mineral and organic soil layer from the field measurement.

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The field experiment was carried out at different locations at the Department of Agricultural & Environmental Engineering, Federal University of Technology, Akure, Nigeria. The primary significance of calibration is to determine the precision and accuracy of the PR2 capacitance moisture meter by matching the value of soil moisture content in percent volume at given measuring depths with the gravimetric method's output.

II. MATERIALS AND METHODS

A. Description of study sites

Experiments were carried out in the Experimental Farm of the Department of Agricultural Engineering, Federal University of Technology, Akure, Nigeria. The experimental field lies at latitude 7o 16’ North and longitude 5o 13’ East at an altitude of 351 m above mean sea level [7]. The soil characteristics of the soil used for the experimentation are listed in Table 1. The experimental soil is categorized as Kaolinitic, iso-hyperthermic, sandy loam, skeletal [8]. The soil dry bulk densities range 0.05–0.5 and 1.0–1.4.5 g cm−3 for the organic and mineral, respectively. The polynomial conversion was used to calibrate the experimental field into minerals and organic soils, as shown in equations 1 and 2. Fig.1 shows the satellite imagery and the map of the study area.

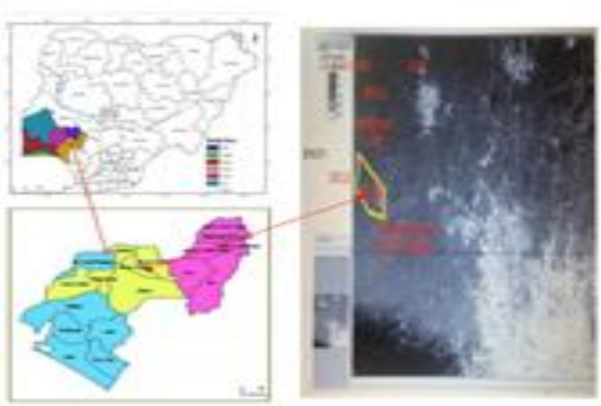
$$Q_m = -0.057 - 0.66V + 8.00V^2 + 42.46V^2 + 14.4V^6 (m^3m^{-3}) \quad (1)$$

$$Q_{org} = -0.023 - 0.72V + 8.72V^2 + 30.44V^3 + 53.71V^4 (m^3m^{-3}) \quad (2)$$

Where, Q_m is mineral soil and Qorg is organic soil and V is the potential voltage.

Table 1: Characteristics of experimental soils

Characteristics	Mineral soil	Organic soil
Bulk density (gcm^{-3})	1.00-1.45	0.05-0.50
Field capacity (%)	21.5-22.6	28.5-31.4
Wilting point (%)	3.00-3.50	4.50-5.00



B. Description of PR2 capacitance moisture meter

The PR2 soil moisture probe is a capacitance-based sensor built around patented sensing technology. It provides unprecedented performance in all soil types, with minimal influence from either salinity or temperature. It is a multi-sensor frequency domain reflectometry probe developed to measure and monitor soil moisture content in field conditions [9]. A pair of sensor rings (upper and lower boundaries) is positioned between each of the six measuring depths, as shown in Fig.2a-b. The PR2/6 has sensing elements at 100, 200, 300, 400, 600, and 1000 mm, and the readings are displayed, stored, and retrieved on the handheld meter (HH2) in m3/m3, %vol, mV, and √Ɛ. The HH2 automatically calculates the water deficit based on the data from the individual sensor of PR2. It gives continuous and instantaneous soil moisture readings. [10] reported that the PR2 Profile Probe could perform repeated measurements at a fixed location or portable to multiple locations with access tubes. The instrument is 1350 mm long and rod diameter of 25.4 mm, and coated with six pair of sensors at preset intervals as shown in Fig. 2a. An auger of 29 mm diameter was developed and used to drill the installation hole. The augering operation was carefully carried out to minimize the soil distortion and ensure the installation hole is straight down. The access tube of 25 mm and 1250 mm was carefully inserted into the hole with a rubber cover. The PR2 Probe was inserted into the access tube (Fig.2c), and the HH2 was connected to the inserted instrument through the USB cord (Fig.2d). The value of soil moisture content at different depths could be obtained from the HH2 by pressing the handheld device button. The soil moisture accuracy is ± 0.06 m^3/m^3 for generalized soil calibration in normal soil. Fig. 2c-d shows the field installation and data reading of the PR2 capacitance moisture meter.

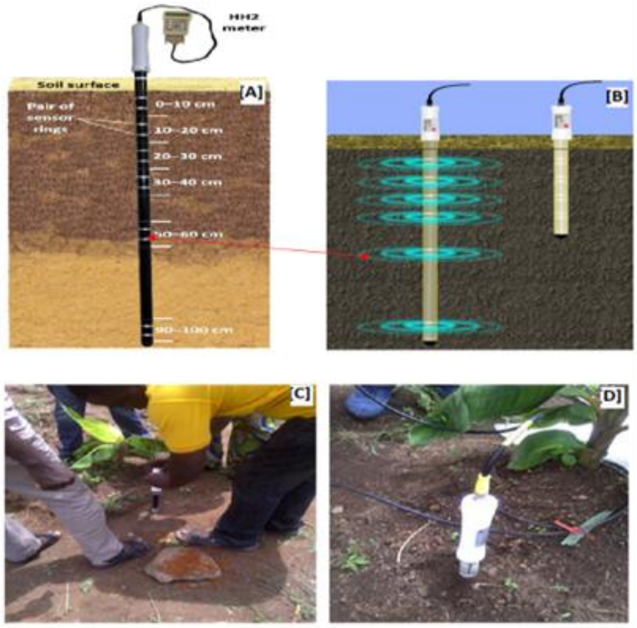


Fig.2: Positioning of sensor rings (a), Electromagnetic reaction of sensors with the surrounding soil (b), Installation of PR2 capacitance moisture meter (c), and PR2 data reading.

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C. Gravimetric soil sampling

The soil moisture content is expressed by weight as the ratio of the mass of water present to the soil sample's dry weight. It can also be expressed in volumetric moisture content as the ratio of the volume of water to the total volume of the soil sample. However, to determine the soil moisture content at a given depth, the soil sample was collected in a moisture can. The wet weight of the sample was recorded. The soil sample was dried in a hot air oven at 105°C until a constant weight was obtained, and the dry weight of the sample was recorded using equation (3). The estimated soil moisture contained is measured in percentage volume.

$$\Theta_m = \frac{SM_{wet} - SM_{dry}}{SM_{dry}} * 100 \quad (3)$$

Where; Θ_m is mass water content, SM_{wet} is soil wet mass, and SM_{dry} is soil dry mass.

The volumetric water content (θv, m^3 m^{-3}) was calculated by converting the mass of water lost on drying, (M_w) relative to the volume, and then dividing by the sample volume using the relationship in equation (4):

$$\Theta_v = \frac{\left[\frac{M_w}{\rho_w}\right]}{V_s} \quad (4)$$

Where, Θ_m is volumetric water content, ρ_w is density of water content (1 Mg m^{-3}).

The PR2 capacitance moisture meter outputs at each depth were compared with the gravimetric soil moisture content measurement. Soil samples were taken at the initial augering process of installing a set of access tubes for the PR2 Profile monitor. The samples were obtained at depths 100 mm, 200 mm, 300 mm, 400 mm, 600 mm, and 1000 mm with four replications on mineral and organic soils. Statistical metrics (sm) such as coefficient of determination (r^2) and root mean square errors (R.M.S.E) were applied. The sm was to determine and explain the difference between the soil moisture content from PR2 at the twist of 180° and 360° relative to the gravimetric moisture content.

III. RESULT AND DISCUSSION

A. Soil moisture measurement

The output of volumetric water content from the PR2 Probe monitor for Site A and B at twist angles of 180o and 360o is presented in Tables 1-4. The soil sample in Site A is organic soil. It is observed that the upper soil layer is the region that contains considerable soil moisture. It decreases proportionally with the increases in soil depth due to continuous water infiltration into the soil layer. Tables 1 and 2 show the outputs of PR2 Probe at twist angles of 180oC and 360°C. The soil moisture values were generally higher at a twist position of 180o, but the difference is not significant at $P< 0.05$. Based on this, the instrument could be applied to monitor soil moisture at varying angles of twist. Tables 3 and 4 show the outputs of PR2 from the mineral soil. The values of soil moisture were lower than the outputs from the organic soil. The clay content in mineral soil is high. It contains small, well-arranged, and banded soil particles that affect water infiltration rate into the mineral soils. The highest corresponding soil moisture values of 23.4% and 21.6% were found at Site A-180o and Site B-180o, whereas the lowest values were found at 2.6% and 2.4% for Site A-180o and Site B-180° at the measuring depth of 1000 mm. It is essential to understand the mechanism of water movement within the soil mass to establish the plant.

Table 1: PR2 at twist angle of 180 for site A

Depth (mm)	MC(vol.%)	MC (v)	MC(√Ɛ)
100	23.4	0.74	1.6
200	17.6	0.61	1.7
300	7.4	0.41	1.9
400	4.6	0.31	2.4
600	2.9	0.27	3.3
1000	2.6	0.24	3.5

Table 2: PR2 at twist angle of 360 for site A

Depth (mm)	MC(vol.%)	MC (v)	MC (√Ɛ)
100	24.60	0.79	1.63
200	18.10	0.63	1.76
300	7.89	0.46	1.93
400	4.93	0.33	2.81
600	3.11	0.31	3.30
1000	2.81	0.29	4.22

Table 3: PR2 at twist angle of 180 for site B

Depth (mm)	MC(vol.%)	MC (v)	MC(√Ɛ)
100	21.55	0.68	1.55
200	16.30	0.56	1.62
300	6.20	0.37	1.73
400	3.94	0.27	2.01
600	2.31	0.23	3.00
1000	2.41	0.20	3.10

Table 4: PR2 at twist angle of 360 for site B

Depth (mm)	MC(vol.%)	MC (v)	MC(√Ɛ)
100	25.10	0.81	1.66
200	18.94	0.68	1.81
300	8.21	0.52	2.04
400	5.30	0.41	3.11
600	3.56	0.36	3.60
1000	3.01	0.34	4.78

B. Calibration and performance evaluation

It is essential to evaluate a sensor-based soil moisture monitor's sensitivity by calibrating it with a standard procedure such as gravimetric soil moisture measurement Tables 5 and 6 present the statistical validation of the PR2 Probe moisture meter. The R.M.S.E. for Site A measurements at the first and second replicates increased from 0.49% to 0.67%. In contrast, an r^2 value of 0.99 was obtained for the two replications when comparing the soil moisture content observed from gravimetric measurement and the automated outputs from the PR2 Probe soil monitor.

The R.M.S.E. values were 0.48%, and 1.32% were estimated for the first and second replications at Site B. The calibration increased the range of V.W.C. estimated by the PR2 probe from 0.5% to 0.6%, which agreed with the observed V.W.C. values (0.4%–0.7%). The results of PR2 Probe calibration are similar to the results obtained by most of the studies, as shown in Fig.3.

Table 6: Statistical validation for PR2

Sites	$R.M.S.E_{grav1-pr2}$	$R.M.S.E_{grav2-pr2}$	$R^2_{grav1-pr2}$	$R^2_{grav2-pr2}$
Site A	0.49	0.67	0.99	0.99
Site B	0.48	1.32	0.99	0.99

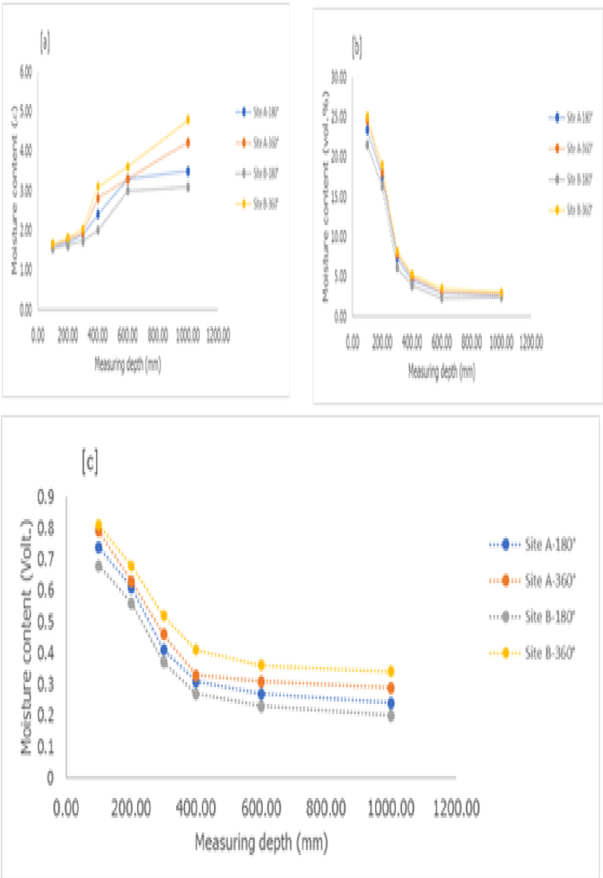

Fig. 3: Relationship between PR2 measuring depths and soil moisture in permittivity (a), %vol. (b), and voltage (c)

IV. CONCLUSION

The overall results of the calibration of the PR2 capacitance moisture meter show a closer and stronger relationship between the soil moisture from the gravimetric measurement approach and the automated moisture meter. The instrument performs very well on mineral and organic soil at different twist angles and measuring depths. The inconsistency between soil moisture estimated by the gravimetric method and the PR2 was reduced by 75.7 % using the site-depth-specific calibration. Therefore, it is concluded that the PR2 Profile Probe could be a reliable alternative to other time-consuming, complex computer algorithms for accurate point measurement of soil moisture.

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