CALIBRATION OF SOIL MOISTURE CONTENT METERS USING THE STANDARD GRAVIMETRIC METHOD

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ABSTRACT

The calibration of the Delta-T Moisture Probe was performed using the gravimetric method as a standard. The variation of soil moisture with depth as determined by the moisture probe and the gravimetric method was analysed for different plots. Soil samples were obtained at different depths and the values obtained from the gravimetric method were compared with those from the Delta-T PR1/6 Moisture Probe. Calibration curves and general equations with respect to soil at different plots for calibrating the moisture meter were constructed and a general calibration equation for the Delta-T PR1/6 Moisture Probe was established. The corresponding generated values were determined from the established calibration equations. The corresponding R^2 values ranged between 0.8081 – 0.9470. Thus, from the experiment, moisture probe predictions were high with a range between 80.8 – 94.7% of the variation captured by the gravimetric method. This investigation establishes the fact that the Delta – T Moisture Probe can be used to carry out soil moisture content determination at different depths on the field.

Keywords: *Soil Moisture content, Moisture Probe, Gravimetric method, Calibration.*

INTRODUCTION

Soil moisture is a critical component of the earth system and plays an integrative role among the various subfields of physical geography. The knowledge of soil moisture and its determination on agricultural lands is important in addressing issues related to soil erosion, flooding and solute transport, growth and yield of agricultural products. Soil moisture content is normally given as a dimensionless ratio of two masses or two volumes. When soil moisture content, given as a dimensionless ratio, is multiplied by 100, the value becomes a percentage on a mass or volume basis. Determination of soil moisture on a volume basis involves finding mass basis figures first, and then the volume basis figures using bulk density are determined thereafter. Considering the variance in soil, some error is nearly always involved in determining bulk density. The amount of water in the soil can also be given as a depth if it were accumulated in a layer. A depth of water is usually used in irrigation. Specification of a depth of accumulated water is usually accompanied by a modifier such as, “in the root zone”.

The Soil Moisture Meter Protocol consists of installing soil moisture sensors at different depths in the soil around the root zone on the agricultural site, reading the soil moisture meter, calibrating the sensors by comparing with a standard technique, creating a calibration curve, evaluating a correcting factor for the moisture meters and re-installation and calibration of soil moisture meters which should be done (after a specific period of time). Usually the knowledge of soil moisture content makes use of some basic concepts. These include field capacity, wilting point, available water and readily available water.

The determination of soil moisture content is a very important tool in field soil tests, irrigation practices, and effective plant water use calculations. However, technological advancement has provided more effective methods of determining soil moisture content. As a result of random errors arising from variability in the samples and methods possibly due to zero errors and reduced efficiency in the meters with time, it is important to compare the data and values obtained from other methods, validate and calibrate these against the standard gravimetric method. Furthermore, for near surface soil moisture measurement, gravimetric techniques are reliable, destructive and tedious. Rapid moisture changes imply frequent sampling and interference with the surface by repeated sampling could be a severe drawback in some studies. In addition to requiring a waiting time for oven drying, direct sampling methods are destructive and disturb measurement areas.

Delta-T PR1/6 Moisture Probe

This is one of the capacitance type sensors for use in plastic access tubes. Although other types of capacitance type sensors are intended for long term data acquisition with sensors fixed in place, the Delta-T PR1/6 Profile Probe is portable with measurements triggered manually by the user. The common characteristics of this type of sensor include the use of a capacitor consisting of two hollow cylindrical metal electrodes arranged coaxially but separated by several millimetres with an insulating plastic, and the use of an electronic oscillator that produces a sinusoidal waveform. The capacitor forms part of the oscillating circuit, and the electrodes are arranged so as to be very close to the inside of the access tube, the idea being that the fringing field of the capacitor will interact with the soil outside of the tube such that the capacitance is influenced by the soil bulk electrical permittivity and thus by soil water content. In this system, the frequency of oscillation decreases as soil water content increases.

The Delta-T PR1/6 is constructed as a cylindrical plastic shaft into which are embedded the capacitor electrodes at pre-fixed intervals. This arrangement is intended for manual data acquisition. In use, the shaft is connected by a cable to a display unit. The shaft is inserted fully into the access tube and readings are taken with a single key press at all of the fixed depths. The PR1/6 has sensors centred at 10, 20, 30, 40, 60 and 100 cm. Data collected using the HH2 moisture meter may be downloaded to a personal computer using the software supplied by the manufacturer. The files are easily input into spreadsheet software. Data are in per cent volume, which are units of $m^3\ m^{-3}$ multiplied by 100. (Delta-T 1999; Miller & Gaskin 2007).

Bell *et al*. (1987) found that the region of influence is restricted to a relatively narrow disc-shaped region surrounding the probe and centred on the gap between the electrodes. The probe is most sensitive to the region immediately adjacent to this gap. This means that the probe is very sensitive to any air gap between the probe, access tube and soil, and that special care must be exercised in installation (Bell *et al*. 1987).

MATERIALS AND METHODS

The Delta-T PR1/6 soil moisture meter is considered in this case study. The farm site for which the field tests were carried out was the Agricultural Engineering Research Farm, located behind the School of Environmental Technology, Federal University of Technology, Akure, Ondo State, Nigeria. Akure, (Latitude 7°14´N and Longitude 5°08´E) is located within the humid region of Nigeria. Akure lies in the rain forest zone with a mean annual rainfall of between 1300-1600mm and with an average temperature of 27°C. The relative humidity ranges between 85 and 100% during the rainy season and less than 60% during the dry season period. Akure which is about 351m above the sea level, has an area of about 2,303sq km, and is situated within the western upland area (Fasinmirin *et al*, 2008). The farm plot measuring 17 m by 46 m and was cut into six blocks of 6 m by 18 m containing three sample plots each. The plots were used for the cultivation of plantain (Musa spp.) supplemented by drip irrigation system.

Field Installation and Testing

The field installation of the Delta-T PR1/6 Profile Probe involved drilling a hole to a determined depth with the use of a spiral soil auger and implanting an access tube into which the moisture probe is inserted for taking readings. The installation kit consists of a spiral soil auger, a hammer, access tube container that protects the moisture probe, a display meter and two cables; for connections to the moisture probe and to the personal computer respectively, computer software CD and an installation manual. The field readings were taken within a period of three weeks.

For the oven drying method, moisture content is determined by measuring the weight of water removed. Drying the moist soil to a constant weight in a drying oven is controlled at 110°±5°C. Temperature of the drying oven is checked frequently to ensure adequate temperature is maintained. The time necessary to reach constant weight will depend upon the type of oven used, the size or depth of the sample and the nature of the soil. A forced draft oven is used; thus, samples were dried for approximately 24 hours. Precautions were also taken to avoid adding wet samples during the last half of the drying period. The weight of soil remaining after oven drying was used as the weight of soil solids. Moisture content expressed as a percent is equal to the weight of water divided by weight of soil solids all multiplied by 100.

Thus, it is not sufficient to report only that gravimetric samples were taken. The units must also be given.
The mass basis water content (θm, $g\ g^{-1}$) is

$$\boldsymbol{\theta m} = \frac{\text{mass of water}}{\text{mass of soil solids}} = \frac{Mw}{Md} \quad \mathbf{1}$$

where Md is the mass of the soil after drying, and $\boldsymbol{Mw} = \boldsymbol{Ms} - \boldsymbol{Md},$ where Ms is the mass of the soil immediately after it is sampled (or before any water is lost).

If the volume of the sample (Vs, m^3) is known, then the volumetric water content (θv, $m^3\ m^{-3}$) can be calculated by converting the mass of water lost on drying to a volume.

$$\boldsymbol{\theta v} = \frac{\text{volume of water}}{\text{total soil volume}} = \frac{\left(\frac{Mw}{\rho w}\right)}{Vs} \quad \mathbf{2}$$

where ρw is the density of water (typically assumed to be 1 Mg m^{-3}).

If the volume of the sample is not known, but the bulk density (ρb, Mg m^{-3}, which is the density of the soil including the pore space but excluding the mass of water, $\rho w = \left(\frac{Md}{Vs}\right)$ of the soil can be estimated, then the volumetric water content can be estimated from

$$\theta v = \frac{\left(\frac{Mw}{\rho w}\right)}{\left(\frac{Md}{\rho b}\right)} \qquad 3$$

Note that Equation 1 is not equivalent to equation 2, where the sample volume was known. In practice, equation 3 often leads to errors. The bulk density value used is typically an average value determined for the soil, and the value may come from a prior study. Because bulk density, like water content, is quite spatially variable, the actual bulk density of the sample may be quite different from the average value.

Data are commonly recorded manually, although computerized weighing systems may be used with modern electronic scales, in which case the data may be made to appear directly in a spreadsheet. Basic data processing is simply a matter of reproducing equations one and/or two in a spreadsheet column. One common error is to aggregate (average) raw data before computing water content values. This practice removes the possibility of plotting the individual water content data for examination of outliers. Examination for outliers is a necessary quality control practice for water content data. This is commonly done by plotting the data sequentially and/or vs. depth. For volumetric data, both the water content and bulk density should be plotted. The bulk density (ρb, Mg m^{-3}) should be calculated in a separate column:

$$\rho b = \frac{Md}{Vs}$$

Compressed samples will have larger than average bulk densities, and dilated samples will have smaller than average values. Both initial and oven-dry masses must be corrected for the mass of the container, often known as the tare weight.

Fig. 1: Plate 1 stainless steel sample containers and weighing Balance

RESULT AND DISCUSSION

The values of moisture content obtained at these depths shows that the moisture content varies increasingly with depth as shown in figures 1 and 2. The percentage moisture content as shown from the field experiment was very small at low depths and increased with increasing depths. Figures 1 and 2 show the relationship between the moisture content measured with the Delta-T PR1/6 Moisture Probe and the depth through the soil. The moisture content is 4.2% by volume at 100 mm depth while at a depth of 1000 mm, the moisture content increased to 25.9% by volume.

Calibration of Soil Moisture Meter

The Delta-T PR1/6 Moisture Probe was calibrated by comparing with gravimetric water content measurements from saturated soil water content to permanent wilting point obtained from conventional oven-dry weights. Calibration curves were constructed for the moisture meter with respect to the Gravimetric method for the six (6) different plot locations: Plots A, B, C, D, E, and F respectively. The general equation for calibrating the soil Delta-T PR1/6 moisture probe was established in each case.

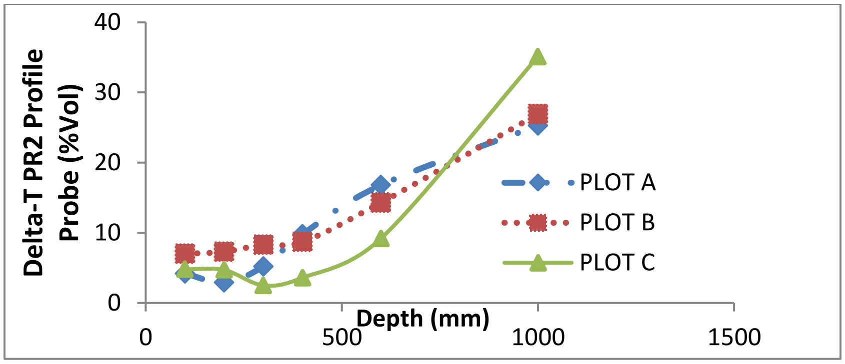

Figure 1. Variation of Soil Moisture Content of Plot A to Plot C with depth.

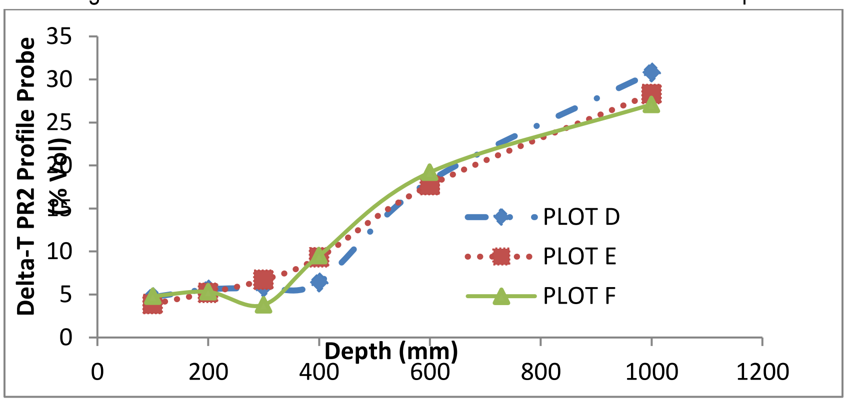

Figure 2. Variation of Soil Moisture Content of Plot D to Plot F with depth.

Table 1: Delta-T PR1/6 Moisture Probe calibration equation for the soil locations

PLOT LOCATION	CALIBRATION EQUATION	R^2 VALUE
A	Y = 0.896x + 2.4214	0.8081
B	Y=2.6379x - 5.5367	0.947
C	Y=2.6115x - 9.831	0.8865
D	Y=2.3005x - 9.0544	0.8635
E	Y=1.1462x + 0.4336	0.9068
F	Y=1.2089x - 1.8819	0.8386

The calibration curve in Figures 3 and 4 shows a close relationship between both soil moisture determining methods at plot A, given by the equation Y=0.896x+2.4214 with a corresponding R^2 value of 0.8081 and at plot B given by the equation Y=2.6379x-5.5367 with a corresponding R^2 value of 0.947. This means that the moisture probe predicted 80.81% and 94.7% of the variation captured by the gravimetric method at plot A and B respectively.

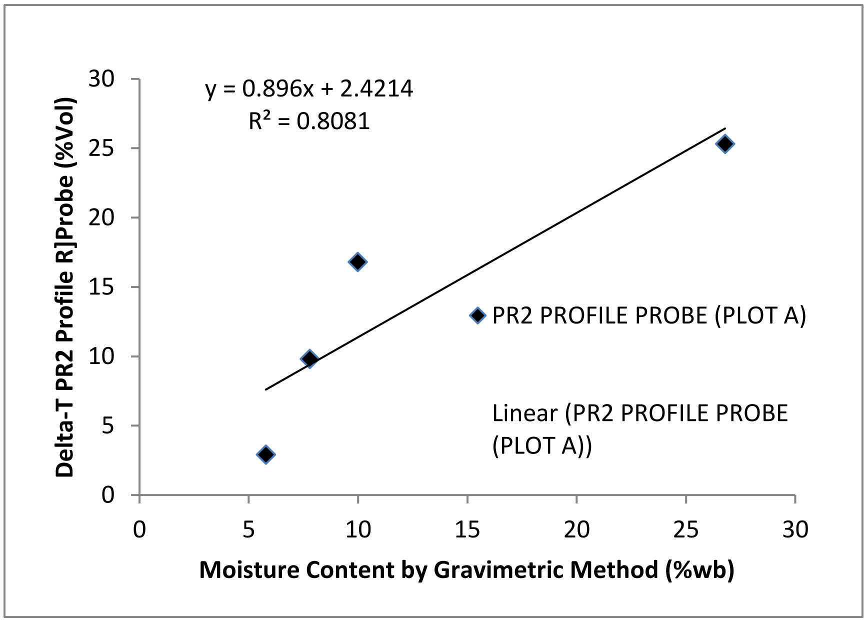

Figure 3. Calibration of Delta-T PR1/6 Profile Probe at Plot A

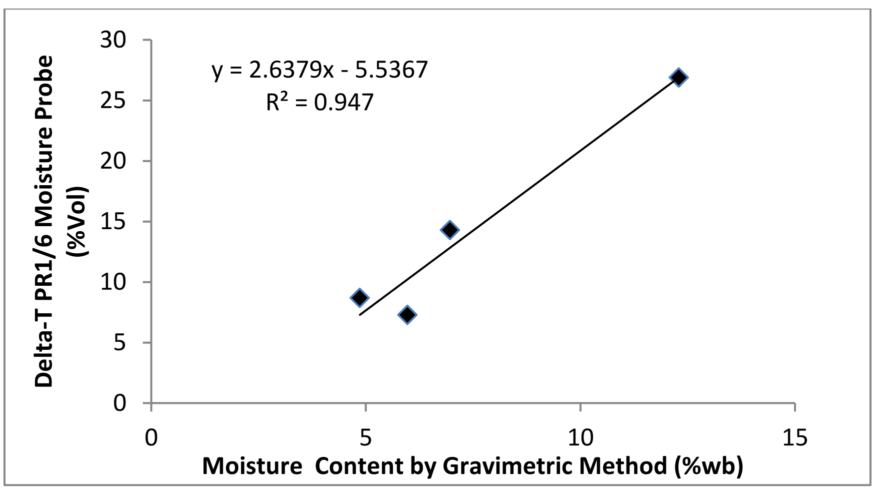

Figure 4. Calibration of Delta-T PR1/6 Profile Probe at Plot B

Calibration of Delta-T PR1/6 Moisture Probe

Calibration equations obtained for all locations with their corresponding R^2 values are presented in Table 1. These value was between 0.8081 to 0.947 with thgeir corresponding equations. A calibration chart was thereafter obtained as shown in Table 2 as well as a chart for the use of the moisture probe.

Table 2: Developed Calibration Chart for Delta-T PR 1/6 Moisture Probe

SOIL PLOT	SOIL DEPTH (mm)	GRAVIMETRIC METHOD (WB %)	DELTA-T PR1/6 MOISTURE PROBE (WB %)
A1	20	5.78	2.9
B1	20	5.97	7.3
C1	20	3.45	6.91
D1	20	5.01	5.6
E1	20	6.91	5.2
F1	20	4.12	5.3
A2	40	7.79	9.8
B2	40	4.86	8.7
C2	40	3.6	9.01
D2	40	9.54	6.4
E2	40	7.8	9.3

F2	40	9.39	9.5
A3	60	9.99	16.8
B3	60	8.12	14.3
C3	60	9.2	8.91
D3	60	11.09	18.2
E3	60	11.35	17.7
F3	60	18.99	19.2

A4	100	26.79	25.9
B4	100	12.29	26.9
C4	100	35.1	16.08
D4	100	16.62	30.8
E4	100	25.21	28.3
F4	100	20.5	27.1

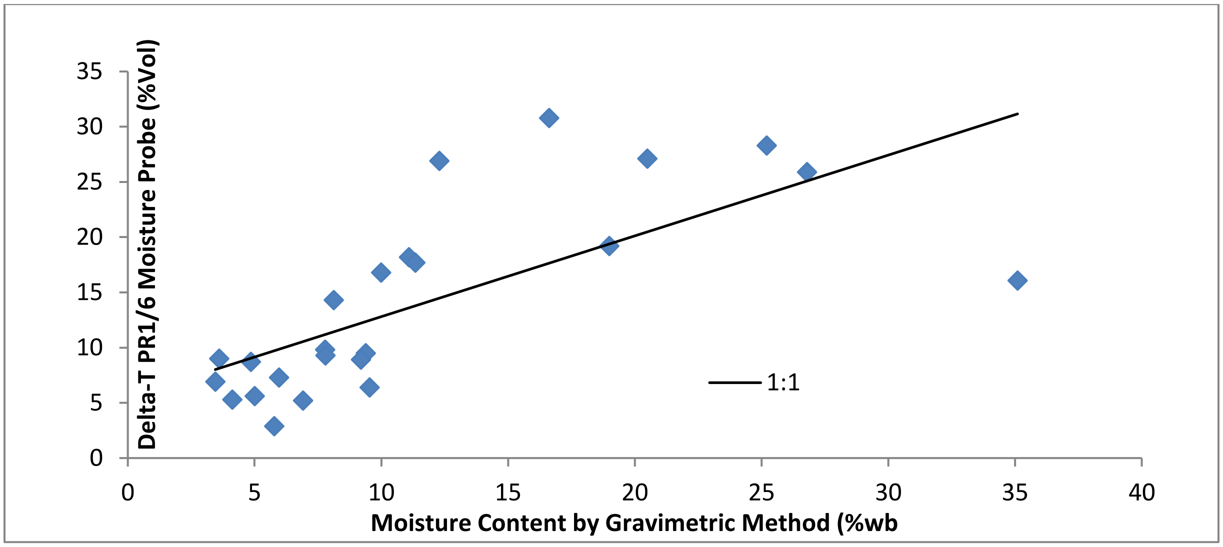

Figure 9. General Calibration grapth for Delta-T PR1/6 Moisture Probe

CONCLUSION

Several studies have shown that the factory calibrations of the capacitance systems are not accurate for all soils (Baumhardt *et al*., 2000; Evett *et al*., 2006). Thus, it is important to calibrate each system for the specific soil in which the sensors will be used. The moisture content measuring instrument Delta-T Moisture PR1/6 probe was calibrated and calibration equations with corresponding curves were developed for the instrument with respect to soil locations.

The generated calibration equations and single universal calibration equations developed from the experimental data set was not entirely accurate. In general, the equations over-predicted relative differences in soil moisture for some soil locations and under-predicted relative soil moisture differences in other location. Also, there were variations in the values of R^2 obtained for the models generated. The models generated are: Y=0.896x + 2.4214, Y=2.6379x - 5.5367, Y=2.6115x-9.831, Y=2.3005x-9.0544, Y=1.1462x+0.4336, Y=1.2089-1.8819 and their corresponding R^2 values ranged between 0.8081 – 0.9470. Thus, from the experiment, moisture probe predictions were high with a range between 80.8 – 94.7% of the variation captured by the gravimetric method. This indicates that the moisture probe predicted values that varies closely ranging between 80.8 – 94.7% of the values captured by the gravimetric method. From this investigation, the Delta – T Moisture Probe can be used to carry out soil moisture content determination at different depths on the field.

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