METER
ENVIRONMENT

METHOD B: SOIL-SPECIFIC CALIBRATIONS FOR METER SOIL MOISTURE SENSORS

Contributors

Method B is a subsampling method following the general procedure for calibrating capacitance sensors outlined by Starr and Paltineanu (2002). The following is a step-by-step instruction guide for performing this method.

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METHOD B INSTRUCTIONS

1. Equipment needed

1.1 **Shovel and bulk soil container** for field soil collection and air drying soil (1 shovel, 1 container for each soil type)

1.2 **Calibration container** (1)

1.2.1 The calibration container should be large enough to pack the soil back to the field bulk density while maintaining enough soil depth to accommodate the full volume of influence of the METER sensor (including the electronics portion).

1.2.2 Different soil sensors may require different-sized containers due to differences in volume of influence and measurement orientation. Please see "Measurement volume of METER volumetric water content sensors" to determine container size.

1.2.3 It is best if the container is relatively rigid and allows clear access to the soil surface.

1.3 **METER sensor and data acquisition system** (1)

1.3.1 METER sensor output is very similar among sensors of the same type. You can calibrate with a single sensor and apply that calibration to other sensors of that type in your soil and maintain excellent accuracy.

1.3.2 Use whatever data acquisition system you plan to use in the field (ProCheck, ZL6, EM60G, EM50, EM5B, Campbell Scientific data logger, etc.).

1.4 **Volumetric soil sampler** (1)

1.4.1 To perform a METER soil sensor calibration, it is possible to use a volumetric soil sampler, which is used to sample known volumes of soil from the calibration container in order to determine volumetric water content.

1.4.1.1 This can be either a commercial soil sampler (such as the ESS Core N' One available from Environmental Sampling Supply) or a homemade sampler. The only requirement for the sampler is that it can collect a soil sample of known volume without changing the soil bulk density.

1.4.2 If you don't have a sampler, we recommend cutting a 3 to 5 cm long section of metal conduit or other small diameter (1.5 to 2.5 cm) metal or thin-walled, rigid plastic tubing.

1.4.3 Deburr both ends of the tubing.

1.4.4 Sharpen one end for easy insertion into the soil.

1.4.5 Precisely measure the length and inner diameter of the sampler.

1.4.6 Calculate the volume ($\pi r^2 h$).

1.5 **Soil drying containers** (10 to 14 per soil type)

1.5.1 The drying containers can be any container that is suitable for oven drying and has a sealable lid (soil sampling tin, baby food jar).

1.5.2 Label containers with a unique number so they can be referenced later.

1.5.3 Measure the mass of each of the clean, dry containers before adding soil to them.

1.5.4 Write down the container label and tare mass in Table 1.

1.6 **A scale or mass balance** to weigh subsamples (1)

1.6.1 The scale should have a resolution of 0.01 g or better for best possible soil-specific calibration.

1.7 **Drying oven** (1)

1.7.1 Any oven that will maintain a relatively stable temperature of 105 to 110 °C will work.

2. Soil sample collection

2.1 Collect approximately four liters (one gallon) of bulk soil.

2.2 Make sure the soil is from the area/depth you wish to measure with your METER sensors.

2.3 You may wish to measure the field bulk density of the soil when you collect your sample.

2.3.1 Use the volumetric soil sampler to collect several soil cores of undisturbed soil. Put lids on all samples to avoid water loss.

2.3.2 Since you've used a volumetric sampler, you know the volume of the soil samples (V_{soil}).

2.3.3 Weigh the samples (no lid).

2.3.4 Record the weight.

2.3.5 Oven dry the soil cores.

2.3.6 Measure the mass of the dry soil (m_{dry}).

2.3.7 Use Equation 4 below to calculate the bulk density of the soil.

3. Soil preparation

3.1 Air dry the soil. Air drying is quickest if the soil is spread in a thin layer and air is moved over the soil.

3.2 Remove large objects from the soil.

3.2.1 The presence of large rocks or other objects can complicate the calibration process. We suggest breaking up large clods and running the soil through a 2 to 5 mm sieve before proceeding.

3.2.2 In some materials (e.g., compost, mulch), it will not be possible to remove large particulates without significantly altering the nature of the material.

4. Calibration method B

4.1 Pack the soil into the calibration container at approximately the field bulk density.

4.1.1 If you start with dry soil, control the bulk density by packing a known mass of soil into a known container volume.

4.1.2 It is generally necessary to add the soil in layers, packing each layer before adding the next.

4.1.3 For the 10HS, only pack a little over half of the soil into the container before inserting the sensor.

4.1.4 For the EC-5, 5TE, and 5TM, GS1, GS3, and TEROS sensors, pack the full soil volume into the container.

4.2 Insert the sensor (EC-5, 5TE, 5TM).

4.2.1 The EC-5, 5TE, and 5TM can be inserted vertically, directly into the full soil container.

4.2.2 **Important**: Insert the sensor tines in a straight line so as not to introduce any air gaps between the sensor tines and the soil.

4.2.3 Insert the sensor fully into the soil. This includes the black plastic base of the sensor.

4.2.4 If you cannot insert the black plastic portion fully into the soil, insert the sensor as far as possible, then take some additional soil and pack it around the remaining portion of the sensor base and a few cm of the cable if possible.

4.2 Insert the sensor (GS1, GS3, TEROS).

4.2.1 Move some soil to prepare a flat spot to insert the sensor into.

4.2.2 Push the sensor into the soil.

4.2.3 Pack soil around the exposed portion of the sensor, being careful to prevent air gaps while maintaining the desired bulk density.

4.2.4 Make sure there is approximately one cm of soil over the top of the sensor.

4.2 Insert the sensor (10HS).

4.2.1 Insert the 10HS sensor as far as possible in the soil container. For some soil types and moisture levels, it is possible to insert the entire length of the 10HS into the soil as with the other METER sensors.

4.2.2 For some soils, it is not possible to insert the full length of the 10HS into the soil column.

4.2.2.1 If you have a METER sensor insertion blade or other blade that is slightly thinner than the 10HS sensor, you can use it to make a pilot hole and insert the sensor fully.

4.2.2.2 If no pilot tool is available, insert the 10HS as far as possible into the soil column. Then, pack soil around the exposed portion of the sensor, being careful to prevent air gaps while maintaining the desired bulk density.

4.2.3 Be sure to get the black plastic portion of the 10HS surrounded by soil.

4.2.3.1 If you cannot insert the black plastic portion fully into the soil, insert the sensor as far as possible, then take some additional soil, and pack it around the remaining portion of the sensor base and a few cm of the cable if possible.

4.3 **NOTE: The sensor should be surrounded by continuous soil for the entire radius of whatever the volume of influence is for your particular sensor. See Measurement volume of METER volumetric water content sensors.**

4.4 Take a sensor reading.

4.4.1 If using non-METER data acquisition equipment, be sure you are exciting the sensor with the same excitation voltage you will use in the field for the EC-5.

4.4.2 All other METER sensors regulate their excitation voltage, so refer to the manual for the appropriate voltage range.

4.4.3 Collect the raw data from the sensor (no calibration applied).

4.4.4 It is a good idea to repeat steps 4.2 to 4.4 once or twice to be sure that you are achieving repeatable insertion quality.

4.4.4.1 Be careful not to insert the sensor into holes you've already made.

4.4.4.2 There will generally be some small variability (a few raw counts or mV), so an average reading can be taken.

4.4.5 Record the sensor readings in Table 1.

4.5 Collect a volumetric soil sample.

4.5.1 Without removing the METER sensor, insert the volumetric soil sampler fully into the undisturbed soil near the sensor.

4.5.2 Remove the sampler, making sure that the soil core inside is intact.

4.5.3 Shave excess soil from the end(s) with a flat edge.

4.5.4 Refill any small voids that may have occurred.

4.5.5 Place the entire soil core into a drying container.

4.5.6 Cap the container. Any water loss from the soil between sampling and the first weighing introduces error to the volumetric water content calculation.

4.5.7 Repeat 4.5.1 to 4.5.6 at least once. This helps to reduce the effects of spatial variability in your sample.

4.6 Measure the mass of each soil + drying container (no lid).

4.7 Record container label and the mass in Table 1.

4.8 Wet the calibration soil.

4.8.1 Add about 1 mL of water for every 10 mL of soil volume.

4.8.1.1 This will increase VWC by 10%.

4.8.1.2 Add the water to the soil as evenly as possible.

4.8.2 Thoroughly mix the soil with your hands or a trowel until the mixture is again homogeneous.

4.9 Repeat 4.1 to 4.8 until the soil nears saturation.

4.9.1 This generally yields 4 to 6 calibration points.

4.9.2 Each point may take up to 1 hour.

4.9.3 Note that the bulk density of the sample can be maintained throughout the calibration process by packing the same soil sample to the same level on the calibration container at each water content.

4.10 Dry the volumetric soil samples.

4.10.1 Place all of the already-weighed, moist samples into the 105 °C oven for 24 hours.

4.10.2 Note that soils with high organic matter content may lose significant volatile organics if dried at 105 °C, leading to error in the calibration. We recommend drying these soils at 60 to 70 °C for at least 48 hours.

4.11 Weigh the dry soil.

4.11.1 Remove the soil drying containers from the oven, and replace covers while still hot.

4.11.2 Allow the soil and containers to cool.

4.11.3 Measure the mass of the dry soil + containers (without lids).

4.11.4 Enter the dry mass into Table 1 taking care to match it with the correct container label.

	Volumetric Water Content Sub Sample 1					Volumetric Water Content Sub Sample 2					Sensor Measurements		
	wet wt + tin	dry wt + tin	tin wt.	Bulk Density	Sample 1 q	wet wt + tin	dry wt + tin	tin wt.	Bulk Density	Sample 2 q	Average q	Sensor 1	Sensor 2
Points	g	g	g	g cm^{-3}	m^3 m^{-3}	g	g	g	g cm^{-3}	m^3 m^{-3}	m^3 m^{-3}	RAW	RAW
Air dry	18.4252	17.9201	1.2252	1.091169935	0.033013072	18.5964	17.9582	1.2564	1.091620915	0.041712418	0.0374	1917.5	1911.1
Point 2	19.8525	17.1252	1.1995	1.040895425	0.178254902	19.9521	17.5258	1.1598	1.069673203	0.158581699	0.1684	2071.9	2049.1
Point 3	21.9958	17.5254	1.2525	1.063588235	0.292183007	21.9585	18.1256	1.2125	1.105431373	0.25051634	0.2713	2264.2	2256.8
Point 4	23.1958	17.6951	1.2255	1.076444444	0.359522876	23.2547	17.9523	1.2465	1.091882353	0.346562092	0.3530	2575.8	2622.4
Point 5	24.9258	17.8529	1.1999	1.088431373	0.462281046	24.9585	17.8754	1.1954	1.090196078	0.462947712	0.4626	2781.9	2781.5

Table 1. Example data collection table for soil-specific METER sensor calibration

Contact support for a Method B Table 1 example.

5. Calculations

The volumetric water content is defined as the volume of water per volume of bulk soil

$$\theta = V_w / V_t$$

Equation 1

Where θ is volumetric water content (cm^3/cm^3), V_w is the volume of water (cm^3), and V_t is the total volume of bulk soil sample (cm^3). V_t of your sample is already known because you used a volumetric sampler to collect the soil samples (see section 1.5). To find V_w, calculate the volume of the water that is lost from the soil sample during oven drying

$$m_w = m_{wet} - m_{dry}$$

Equation 2

$$V_w = m_w / \rho_w$$

Equation 3

Where m_w is the mass of water, m_{wet} is the mass of moist soil (g), m_{dry} is the mass of the dry soil, and ρ_w is the density of water (1 g/cm^3). In addition to the volumetric water content, the bulk density of the soil sample can also be calculated. Bulk density (ρ_b) is defined as the density of dry soil (g/cm^3)

$$\rho_b = m_{dry} / V_{soil}$$

Equation 4

The calculations above are most easily done in a spreadsheet program such as MS Excel. The previous Table 1 shows the above calculations performed for method B.

The output of the METER sensors is not very sensitive to small differences in soil bulk density. However, if the bulk density of the soil during calibration is radically different from that of the field soil, it will introduce error into the calibration. If you measured the field bulk density as described in section 2.3, you can control the bulk density of the soil in the calibration container to that level (see section 4.1.1). If the soil is not packed to a known bulk density and the bulk density in the calibration container is different from the field bulk density by more than about 20%, consider repeating the calibration while packing the soil to a more realistic bulk density.

6. Finding and using the calibration function

If the above calculations are performed in a spreadsheet program, then finding the calibration function is quite easy. Simply make a scatter plot with the sensor output on the X-axis and the calculated VWC on the Y-axis (Figure 1). Then use the trendline or curve-fitting function to construct a mathematical model of the relationship. This relationship is often linear, as shown below, but it is sometimes best fit with a quadratic equation, especially in soils with high organic matter content.

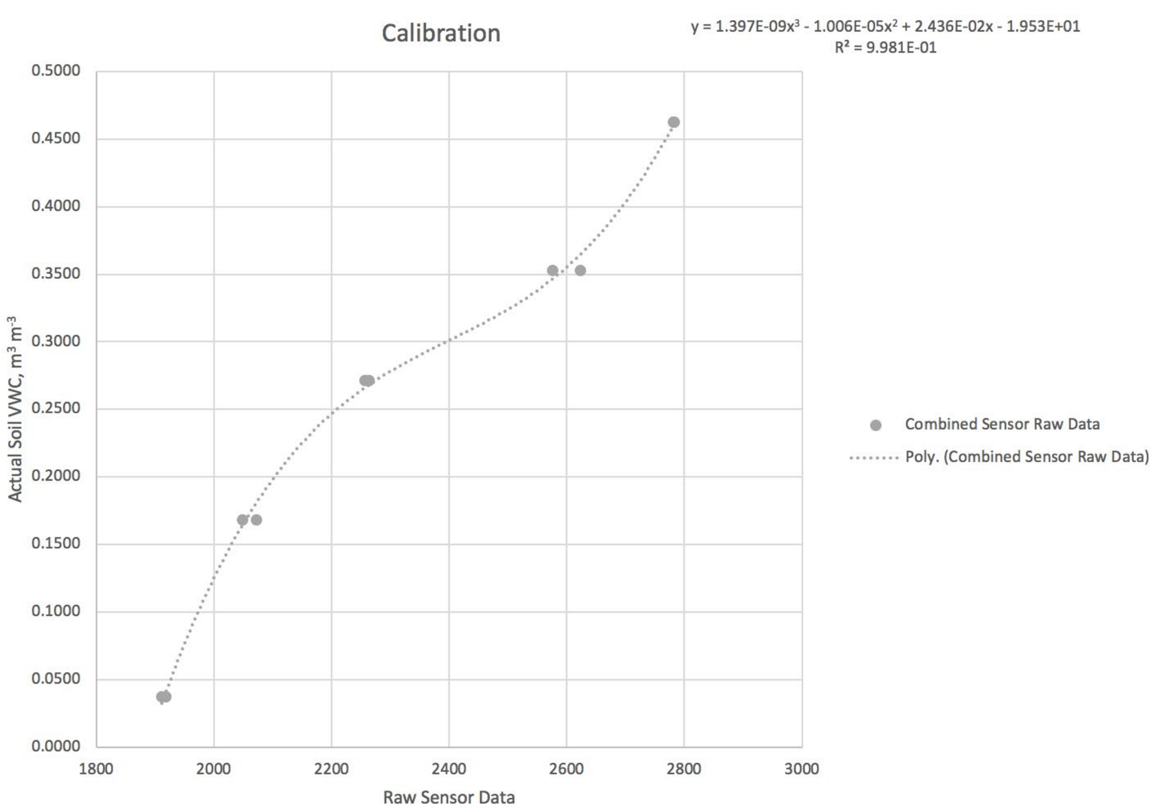

Figure 1. Plot of example calibration data. The soil specific calibration equation is shown in the upper right corner of the graph area.

Once the calibration function is constructed, apply it to the METER sensor data. When logging data with the ZL6, EM60G, EM50, and EM5B data loggers, apply this equation to the raw data downloaded from the logger. If using ZENTRA Cloud software, apply the calibration function under the 'System Settings' tab in the 'Calibration Settings'. Simply click the 'Add Calibration' button and type in the coefficients. Remember to apply enough significant figures to the equation. If using the DataTrac software package, apply the calibration function under the setup tab. If using Campbell Scientific data loggers, apply the calibration in the data logger program or during post-processing.

REFERENCES

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