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Calibration of Watermark soil moisture sensors for soil matric potential and temperature

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Abstract

Rapid, accurate, and automated measurement of soil matric potential is desirable. Evidence suggested that the Watermark resistance block might be an appropriate and inexpensive tool, so we conducted an evaluation of its relevant characteristics. A number of these blocks were calibrated under laboratory conditions to determine their individual and aggregate responses to soil matric potential, soil type, and temperature. We found that the temperature response could be expressed as a single equation, valid for all tested blocks, but comparison against matric potential revealed that each block had a characteristic response. Furthermore, block responses were different in two soils and, for a given soil, not necessarily reproducible. Given these limitations, these sensors are probably useful only as relative indicators of soil water status.

Introduction

Studies involving water transport in the soil-water-plant continuum require knowledge of the energy status of soil water. A number of techniques for measuring soil water potential are available. All require that some medium, whose water potential can be measured or inferred, be equilibrated with soil water. The soil water potential is then found from the known water potential of that medium (Campbell and Gee, 1986).

Electrical resistance blocks have been used for many years to estimate soil water status (Hillel, 1980). These date from the work of Bouyoucos and Mick (1940). The underlying principle is that the electrical resistance of the block changes as the water content of the block changes. The matric potential of the block is derived from this measurement of the electrical resistance of the block, given a previously determined relationship between electrical resistance and water potential of the matrix. Advantages of resistance blocks are that they are relatively inexpensive, do not require maintenance, and can be read electronically with simple data acquisition systems. Nonetheless, disadvantages are their sensitivity to salinity and temperature, and the change of the sensor's matrix characteristics with time.

The Watermark* soil moisture block (Larson Co., Santa Barbara, California) is sold as a qualitative indicator of soil moisture for applications such as irrigation scheduling. It consists of two concentric electrodes embedded in a porous matrix containing a soluble salt ($CaSO_4$), so that the water in the porous matrix is always gypsum-saturated. Lead wires are connected to the elec-

* Mention of trade names is for the convenience of the reader only and implies no endorsement on the part of the University of Minnesota or USDA-ARS.

trodes so that the electrical resistance of the porous medium can be measured. The device is encased in a synthetic membrane supported by PVC plastic. This presumably confers a life expectancy longer than that of gypsum blocks, which dissolve over time.

As temperature increases resistance decreases. Block resistance as measured in the soil should therefore be corrected for temperature, which implies normalizing the measured resistances to a reference resistance at an arbitrarily chosen temperature. Campbell and Gee (1986) reported a typical temperature sensitivity of 3% K^{-1}. The manufacturer of the Watermark sensors reports a temperature sensitivity of 1.8% K^{-1}. One calibration for soil matric potential, independent of soil type and assumed valid for all blocks, is provided by the manufacturer. It presents a nearly linear relationship between matric potential and resistance. Armstrong et al. (1985) calibrated a number of Watermark (model 200) soil moisture sensors in two soils and reduced the data to a single non-linear equation relating measured sensor resistance to matric potential and temperature.

The objectives of this study were to calibrate the Watermark sensors against matric potential and so determine whether a single calibration could be used for all sensors. We also sought to determine whether such calibrations were soil-dependent, whether they were reproducible, and to assess the temperature sensitivity of the Watermark sensors.

Materials and methods

Temperature calibration

A PVC pipe, 0.15 m diameter and 0.45 m tall, was packed with Waukegan silt loam (fine-silty, mixed, mesic Typic Hapludoll). During packing, two soil moisture blocks (Watermark Model 200 Soil Moisture Sensors) and 3 thermocouples were installed at each of three different depths in the sample, at 0.33, 0.22, and 0.11 m. The blocks had previously been subjected to several drying and wetting cycles, as recommended by the manufacturer. The PVC container with soil was sealed to maintain constant moisture content and then placed in an insulated container. Temperature in the container was controlled by a circulating water bath.

Blocks and thermocouples were multiplexed to a datalogger (Campbell Scientific AM32 multiplexer and 21X logger, Logan, Utah). Block resistance was obtained by wiring the block in an AC half bridge, subject to an excitation voltage of 500 mV. A 1 kΩ precision resistor in series with the blocks served as a reference resistor. AC current is required to prevent polarization of the electrodes in the block. Temperature was increased in 5°C increments from 5 to 40°C. Temperature in the soil was measured continuously. After soil temperature had stabilized for more than 12 hours following each step increase, the resistance of each block was measured.

Soil matric potential calibration

Calibrations for soil matric potential were conducted in two different soils. The first calibration was conducted in the summer in a greenhouse. Waukegan silt loam was well mixed with water to a slurry, which was then poured into a plastic-lined plot of 1.2 by 1.2 by 0.18 m deep, so that soil variability was minimized. Five tensiometers, 36 moisture blocks (Watermark Model 200 Soil Moisture Sensors), and four thermocouples were installed in a uniformly spaced pattern at the same depth, with the center of each sensor at 0.09 m depth. All sensors were inserted in the slurry, which allowed easy installation and good contact between soil and sensor. The physical dimensions of the blocks (20 mm diameter and 50 mm long) were identical to those of the ceramic cups of the tensiometers, so that they covered the same depth in the soil.

The second calibration was performed in a laboratory. A 0.5 by 0.6 by 0.25 m deep box was filled with a slurry of saturated Hubbard loamy sand (sandy, mixed Udorthentic Haploboroll). Twenty blocks from among those used in the first experiment were randomly selected and installed, together with four tensiometers and two thermocouples. Depth to the center of each sensor was 0.12 m. To investigate calibration reproducibility, this second experiment was repeated by reinstalling the same sensors in the same soil.

In all three experiments, pressure transducers were attached directly to tensiometers and connected to a datalogger (CSI 21X). Blocks and thermocouples were wired to a multiplexer, which was connected to the same datalogger. Measurements were made every 30 minutes. The blocks were soaked in water before installation, as was recommended by the manufacturer. The soil was dried by slow, continuous evaporation at the soil surface. In the laboratory experiment this was aided by a fan. The experiment was continued until air entered the tensiometers, which occurred after 16 days in the first experiment, 3.5 days in the second, and 6 days in the third. Hence, the range from saturation to a matric potential of approximately −80 kPa was covered.

Results and discussion

Temperature calibration

Observed resistances from the six blocks showed similar relations to temperature, as presented in Figure 1. Each data point in Figure 1 is an average of six readings. Since no significant radial temperature differences in the sample were observed (<0.1 K), the three temperature measurements at each depth were averaged. Temperature differences in the vertical dimension were accounted for, but did not exceed 0.4 K.

Normalizing measured block resistance (R_m, kΩ) obtained at temperature T_m (°C) to a reference resistance (R_r, kΩ) at temperature T_r (°C) was accomplished using

$$R_r = R_m[1 + a(T_m - T_r)]\,. \quad (1)$$

Campbell and Gee (1986) reported $a = 0.03$ as a typical value for resistance blocks. The manufacturer of the Watermark block lists $a = 0.018$, yielding the dashed line in Figure 1. Regression through our data resulted in $a = 0.024$ with T_r = 25°C. Armstrong et al. (1985) used a different mathematical expression for their regression, but the resulting temperature correction was numerically similar to the one found in this study. When applying the different temperature correction factors to observed block resistances, the discrepancies are small and insignificant compared to other uncertainties, as will be shown below.

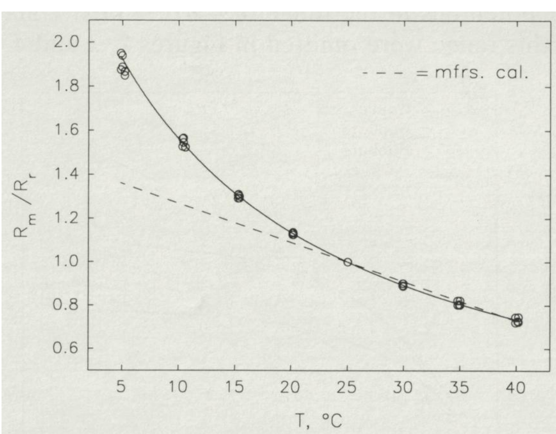

Fig. 1. Measured resistance as a function of soil temperature for six Watermark blocks. *Data points* are averages of six measurements. Standard deviations for six readings were less than 0.01. R_r is the normalized resistance at T_r (25°C). The dashed line represents the manufacturer's suggested correction.

Soil matric potential calibration

In all three experiments, measured soil matric potentials from the tensiometers agreed well, indicating that the soil dried uniformly in space. Soil matric potential data within each experiment were therefore pooled. Measured block resistances were corrected for temperature according to Equation 1. Two blocks did not yield meaningful readings and were discarded.

Figure 2 shows the calibrations for soil matric

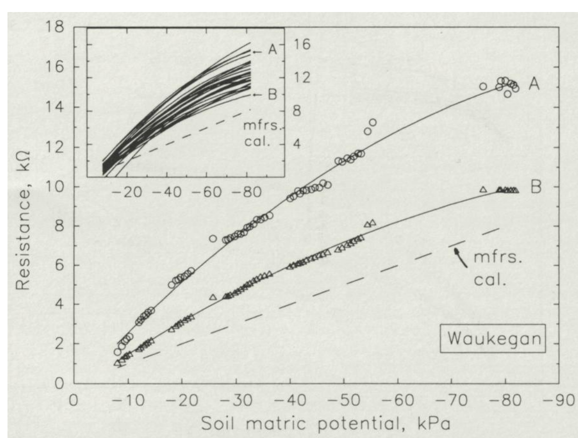

Fig. 2. Block resistance versus soil matric potential data for two blocks (**A** and **B**) in Waukegan silt loam. The dashed line represents the calibration provided by the manufacturer. The inset shows calibration curves for all 34 blocks.

potential in the Waukegan silt loam. The inset presents calibration curves for all 34 blocks. Resistance versus matric potential data for two example blocks A and B are shown in detail. The dashed line represents the calibration provided by the manufacturer. Figure 2 demonstrates that the calibration for each block individually was satisfactory ($R^2 > 0.98$ for a second-order polynomial fit), but that the use of a common calibration for all blocks could lead to substantial errors. For instance, an observed resistance of 9 kΩ corresponds to soil matric potentials ranging from −70 to −37 kPa. Others (Hanks and colleagues, Utah State University, pers. comm., 1990) have tested several electrical resistance blocks for soil matric potential. They also found that the three Watermark blocks they tested each possessed decidedly different calibrations. The differences were, however, smaller than for most other types of resistance blocks they tested.

Calibration curves for soil matric potential in the Hubbard loamy sand for the same blocks A and B are shown in Figure 3. As for the Waukegan silt loam, individual calibrations were quite good ($R^2 > 0.99$ for a second-order polynomial fit), but a common calibration again produces unacceptable results. Tensiometer data showed that the soil was at a uniform matric potential at each time.

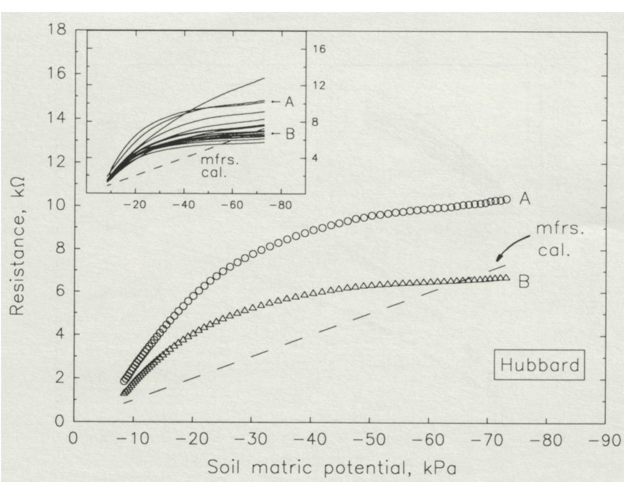

Fig. 3. Block resistance versus soil matric potential data for the two blocks (**A** and **B**) in Hubbard loamy sand. The dashed line represents the calibration provided by the manufacturer. The inset shows calibration curves for all 20 blocks.

Figure 4 presents the calibrations for the two blocks A and B in each of the two soils, and it is clear that the resistance-potential relations differ significantly between soil types. Figure 4 also shows that duplicate calibrations using the same blocks in the same soil do not coincide. The poor repeatability in the calibration inhibits any conclusion to be drawn about the soil-specific nature of the block response. This is in contrast to the results of Armstrong et al. (1985) who reported that one calibration adequately described the response of Watermark 200 sensors to soil matric potential in two different soils. They used a sandy topsoil and clay subsoil of a Norfolk soil. One might argue that the blocks in the second run in the Hubbard loamy sand could not keep up with the declining matric potential in the soil, which could explain the flatter shape of the calibration curves. This argument is ruled out, however, since the second run in the Hubbard loamy sand lasted longer (6 days) than the first run in the same soil (3.5 days). Hanks (pers. comm., 1990) conducted duplicate calibrations of three Watermark blocks and also found poor repeatability in the two runs.

Generally, blocks did not respond to changes in soil matric potential at potentials higher than approximately −8 kPa in either soil, which is in agreement with the upper limit of −10 kPa given by the manufacturer. Figure 5 shows typical block resistance as a function of matric potential for potentials in the range of 0 to −8 kPa. Data in this range were omitted in Figures 2, 3 and 4.

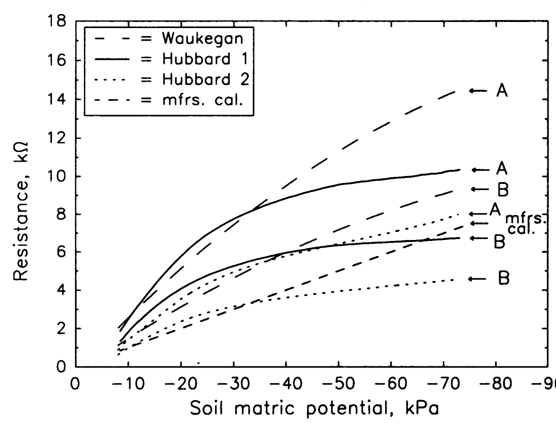

Fig. 4. Calibration curves for soil matric potential for the same two blocks (**A** and **B**) in Waukegan silt loam and Hubbard loamy sand. Hubbard 1 and 2 represent duplicate calibrations.

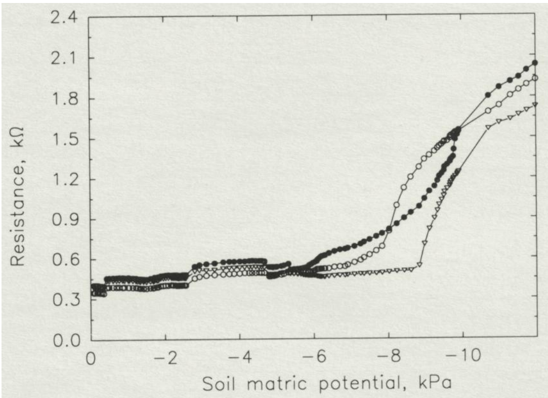

Fig. 5. Typical block resistance versus soil matric potential for matric potentials in the range of 0 to −10 kPa.

Conclusions

The sensitivity of electrical resistance to soil temperature was the same for all Watermark blocks. Calibrations for soil matric potential were unique for each block, and different in two soils. More serious, repeated calibration of selected blocks in the same soil produced different results. Consequently, no conclusions can be drawn about the soil-specific nature of the block response.

We conclude that Watermark sensors are not suitable for accurate, reproducible measurements of soil water potential. Their use is appropriate in cases where relative indications of soil wetness are sufficient, which apparently was their intended use.

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