Advances in Determining Soil Matric Potential Using an Engineered Porous Ceramic and Dielectric Permittivity

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Introduction

Soil water potential is a key parameter for determining water availability for plant growth, water flow, and soil stability. Although an in situ measurement of soil water potential has been the focus of considerable research over the years, existing solutions still have many draw backs such as high maintenance, limited longevity, individual calibration requirements, high cost, and small measurement range. The objective of this research was to develop a sensor that could be used in the field to accurately measure in situ soil water potential without the limitations noted above.

Sensor Design

When a porous material (ceramic) is put in contact with the soil, water will flow into or out of that material until it reaches equilibrium. At equilibrium, the energy state of the water (water potential) in the ceramic and in the soil are equal. As with any porous material, ceramic has a unique, static relationship between the amount of water in the matrix (water content) and its water potential, called a moisture characteristic. The water potential sensor (MPS-1) measures the water potential of the soil by equilibrating a ceramic matrix with the soil, measuring the dielectric permittivity of the ceramic to find its water content, then calculating the water potential through the moisture characteristic relationship. Instead of converting the sensor output to dielectric and then water content, correlations are made directly between sensor output and water potential.

Laboratory Calibration and Characterization

The most effective method for calibrating the MPS-1 utilized 1 and 5-bar pressure plates. Other methods provided useful points on the calibration curve (wet – tensiometer, dry – thermocouple psychrometer, chilled mirror hygrometer) but did not cover a wide enough range. Sensors were packed into saturated soil on 1 and 5-bar pressure plates and allowed to equilibrate for at least 48 h at a variety of pressures. Two soil textures (sandy loam and silty clay loam) were tested to ensure sensor calibration was constant in differing soil types. Two revisions of the sensor were used in the calibrations (R2.06 and R2.07); R2.06 allowed more electromagnetic field (for the dielectric measurement) to leak into the surrounding soil.

After calibration, sensors were installed in a silt loam together with tensiometers to show relative response time and water potential range. Wheat was grown in the soil under sodium grow lights to simulate field water use conditions.

Sensors were also tested to determine their sensitivity to electrical conductivity. To do this, the ceramic disks were vacuum saturated in solutions with a range of electrical conductivities and compared.

Results and Discussion

A time series of sensor equilibration on a pressure plate over a range of pressures is show in Fig. 1. Sensor calibration data were derived from the equilibrated sensor output at each chamber pressure.

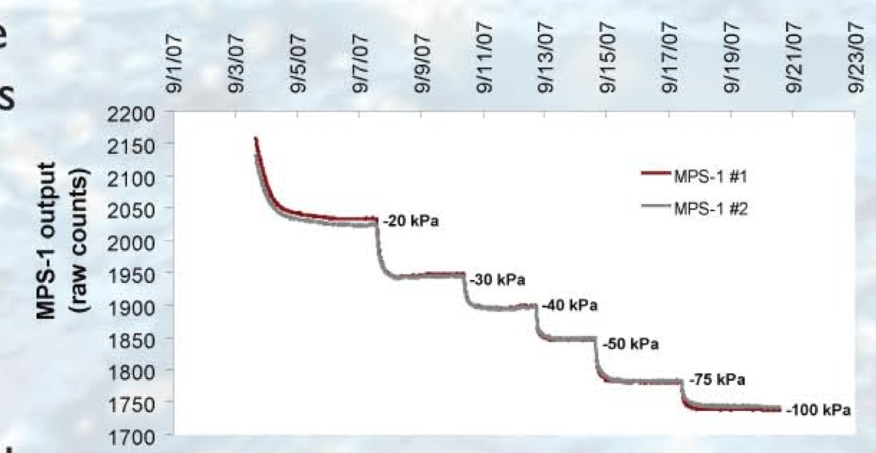

Figure 1. Time-series MPS-1 calibration data collected in silty clay loam soil in 1 bar pressure plate apparatus. C hamber pressure settings are shown at each step.

Ideally, the MPS-1 would have the same calibration curve, regardless of soil type. R2.06 showed differences between the sandy loam and silty clay loam calibration (Fig. 2a and 2b). Subsequent tests indicated that some of the electromagnetic field intrinsic to the dielectric measurement was leaking out of the ceramic into the surrounding soil, suggesting differences in the two soil calibrations were caused by differences in water content between sandy loam (lower) and silty clay loam (higher) at the same water potential.

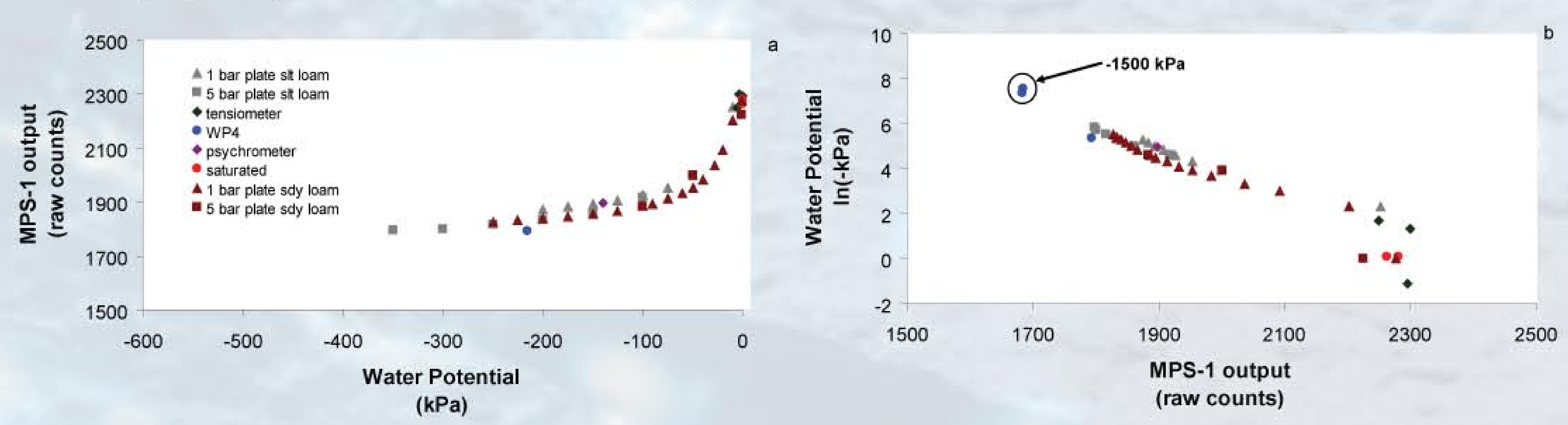

Figure 2 a&b. Calibration data collected for MPS-1 R2.06 a) plotted with linear axes, and b) plotted with water potential units in logarithmic increments. Note that the axes are inverted between the two figures to allow a calibration function to be derived for the semi-log data (not shown).

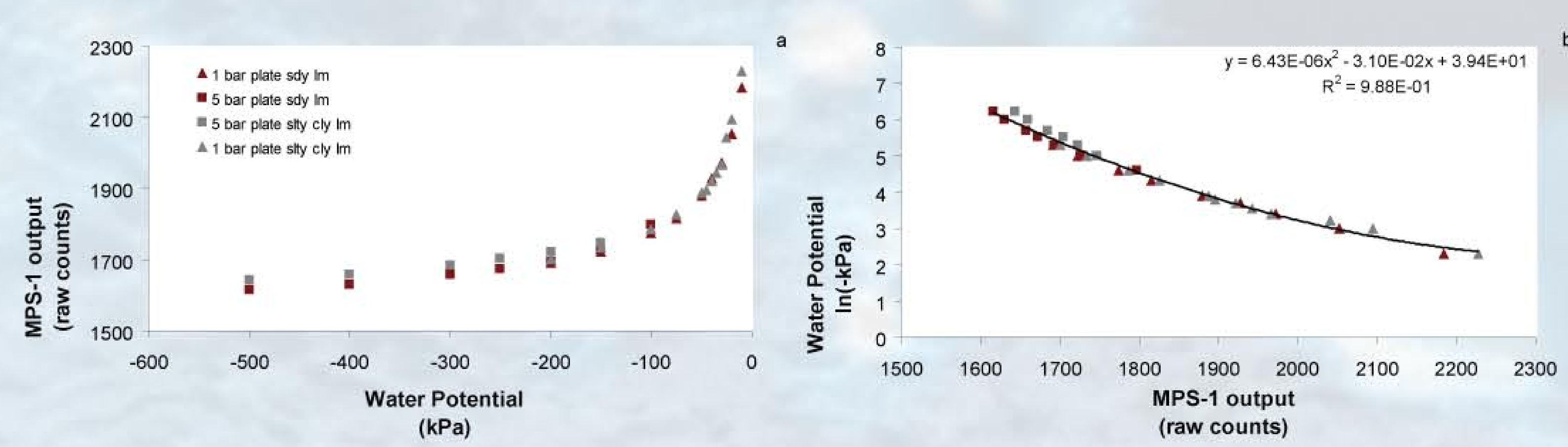

Figure 3 a&b. Calibration data collected for MPS-1 R2.07 a) plotted with linear axes, and b) plotted with water potential units in logarithmic increments. Note that the axes are inverted between the two figures to allow a calibration function to be derived for the semi-log data (shown in upper right corner of Figure 3b).

The MPS-1 was revised to better contain the EM field within the ceramic (R2.07) and recalibrated. The new sensor (R2.07) was much more effective at containing the EM field which resulted in smaller differences in the two soil calibration lines (Fig. 3a and 3b). Semi-log plots of the calibration data show a linear relationship between sensor output and water potential as expected (Fig. 2b and 3b). According to the calibration data, the MPS-1will work well from an air entry water potential of around -9 kPa down to approximately -500 kPa with higher sensitivity at higher (less negative) water potentials.

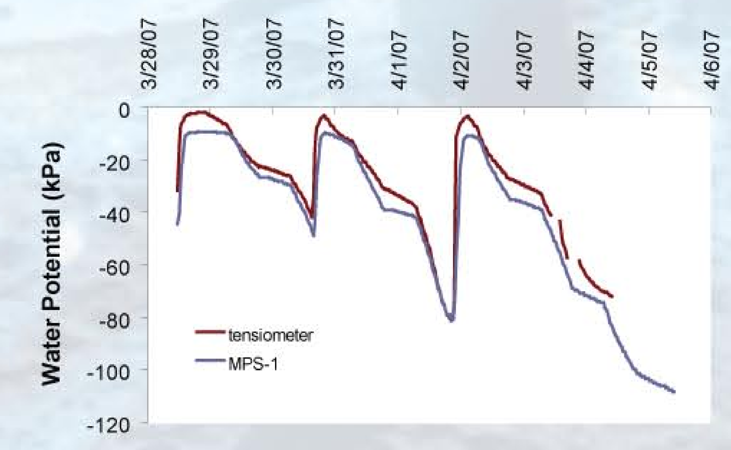

Figure 4. Time-series water potential measured with a calibrated MPS-1 and a tensiometer over several drydown and re-wetting cycles in an agricultural soil under wheat. Note that the tensiometer cavitates on 4/4.

Combined MPS-1 and tensiometer data in a silt loam are showing in Fig. 4. Both sensors respond similarly in magnitude and speed to watering events and diurnal water use. These data suggest that the MPS-1 will respond quickly to changes in water potential in the soil.

Electrical conductivity had little effect on sensor output from 0.1 to 5 dS m-1 (Fig. 5). Maximum MPS-1 change was 0.9% compared to a control. Earlier revisions of the sensor using a lower measurement frequency (5 MHz, data not shown) indicated considerable electrical conductivity sensitivity so the increase in measurement frequency (70 MHz) seems to solve this issue.

Conclusion

The MPS-1 (R2.07) performed well in our tests. Calibration was consistent between two soil types and with a variety of calibration techniques. Equilibration at static and dynamic water potentials was relatively fast and similar to a tensiometer under simulated field conditions. In addition, MPS-1 output closely approximated the tensiometer and showed much greater water potential range.