Response of the ECH_2O EC-10 and EC-20 Soil Moisture Probes to Variation in Water Content, Soil Type, and Solution Electrical Conductivity

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Introduction

Researchers familiar with commercial water content probes will often ask three questions when approached with a newly developed dielectric sensor: what is the accuracy of the instrument, how does it react to differing soil textures and electrical conductivity, and how much does it cost? In fact, the first two questions are closely related, as often the properties of a soil can determine the accuracy of volumetric water content reading from a dielectric probe. Poor results from probes that measure dielectric in soils with high electrical conductivity and salinity are well documented.

The third question has considerable importance as well because the cost of water content sensors can limit the number of sites where water content is monitored. The ECH_2O probe, a new, inexpensive dielectric sensor developed by Decagon Devices, Inc. uses specialized circuitry to measure the dielectric of media surrounding a thin, fiberglass-enclosed probe. The objective of the experiment was to determine the calibration of several dielectric probes with respect to soil water content and examine the effects of soil texture and salinity on the stability of that calibration.

Table 1 Textural and salinity analysis for soils used in soil water content analysis

Soil Type	Sand %	Silt %	Clay %	EC (mmho cm^{-1})
Loamy sand	87	3	10	0.04
Sandy loam	79	9	12	0.34
Loam	47	29	24	0.09
Silt Loam	*	*	*	0.20
Silt Loam	3	71	26	0.12
Silty Clay Loam	3	68	29	0.09
Silty Clay	17	41	42	1.48

Methods

Six soils with differing textures were collected and allowed to dry in air for several weeks. Soil textures included loamy sand, sandy loam, loam, silt loam, silty clay loam, and silty clay (artificially mixed) (Table 1). We manually crushed each sample to break up large peds and allow uniform packing. To test the dielectric probes response to changing water contents, tap water (electrical conductivity (EC) < -1 0.1 mmho cm^{-1}) was mixed with soil to make at least four different water contents for each soil type. Soil was then packed around the dielectric probe in a 30 cm x 15 cm x 15 cm container. Although bulk densities often increased with increased volumetric water content (θ), care was taken to standardize packing densities. Voltage outputs of probes packed in soil were recorded at each water content.

Salinity effects on probe output were also considered. To test the effect of higher EC, we made solutions of approximately 3.3 mmho cm^{-1} and 12.9 mmho cm^{-1} EC by adding 2 and 8 g, respectively, of NaCl to 1 liter of distilled water. These solutions were added to each soil type and measurements of θ and probe output were recorded for several water contents.

Seven dielectric probes were tested on each soil type and θ to determine the stability of calibration between probes. An ECH_2O sensor requires a fixed excitation voltage that produces an output voltage proportional to the dielectric of the medium surrounding it. A 20 ms excitation voltage was supplied to each sensor and the output voltage recorded. Four different excitation voltages, 2.5 V, 3 V, 4 V, and 5 V, were used to determine the effect of input voltage on probe output. Actual θ was calculated for each soil/water mix. Volumetric soil samples were collected using a hollow cylinder (16 cm^3) and dried using a microwave oven for 10 min. Volumetric water content was determined using the difference in weight before and after drying, the soil weight, and the volume of the soil sample. Three samples were taken for each soil to evaluate θ.

Water content versus probe output data was plotted for each probe and soil type. Ideally, a standard calibration would apply to all soil types and salinities, so a single regression was plotted and any large deviations considered. In addition, differing input voltages were compared to consider bias in probe output based on excitation voltage.

Results and Discussion

Dielectric probes were found to have a near linear relationship to θ for all soils tested (Fig. 1). Some scatter can be seen in the data, which is due in part to difficulties obtaining accurate measurements of θ. Dielectric sensors have a limited volume of measurement that decreases considerably with distance from the surface of the probe. Because it was likely that there were differences in bulk density between soil adjacent to the probe and at the soil surface, our inability to measure water content directly at the surface of the probe may have led to errors in actual θ.

A regression line through data for soil types with low to moderate sand content shows good correlation between θ and sensor output (Fig. 2). However, the trend of the data from sandy loam and loamy sand both exhibits regular bias in probe output that is separate from the random variation above and below the mean exhibited by other soils (Fig. 3). While the output of the sensor remains linear with θ, these data suggest soils with high sand content would benefit from individual calibration. Soils with high clay contents are also of interest because they have been shown to cause large errors in some dielectric sensor measurements. Our data show very little dependence of the ECH_2O sensor on soil textures with moderate percentages of clay (Fig. 1).

Applying a 3.3 mmho cm^{-1} solution to soils did very little to shift the overall calibration line (Fig. 4) for soils with low to moderate sand contents. Figure 4 indicates the increased electrical conductivity of the soil solution did not shift the majority of the data outside the scatter of the tap water θ. However, when solution EC was increased to 12.9 mmho cm^{-1}, deviations from the standard calibration are much more apparent.

A calibration shift was much more evident in the measurements on sandy loam and loamy sand (Fig. 5). Bias in individual sensor output was insignificant for all probes tested. Using recorded outputs at each soil water content, scatter plots were made to compare individual probe output at a given θ with all other sensor outputs at the same θ. Figure 6 shows an example of sensor versus sensor plot and regression. Regression lines for all probes showed a maximum of < 4% deviation from unity, suggesting that calibration is not probe-specific. This result is important as it allows standard calibration functions to be applied to multiple probe outputs when multiplexed.

Excitation voltage had no affect on the linearity of probe output. However, increased excitation voltage did reduce the sensitivity ($\Delta\theta$ per unit mV) of the probe 10, 16, and 21% for 3, 4, and 5 V excitation, respectively, compared to the 2.5 V input. Often, data recording devices are limited the range of input voltages that can be provided, so the flexibility of probe excitation is a common concern. These results suggest that higher excitation voltages can be supplied to the probe with only a small loss of sensitivity.

Summary

Probe output was shown to be linear with θ for all soil tested, but soils with high sand content had regressions that were considerably different from those of other soil types. Combining probe readings and θ for all soils, we found that a standard calibration curve could be used to evaluate water contents to within ± 3% θ for soils with low to moderate sand content. For soils with high sand content, soil-specific calibrations would be required for accurate measurements. Increasing soil solution EC had a small effect on probe output. Again, for soils with high sand content, that effect was much more pronounced, especially at solution electrical conductivities of 12.9 mmho cm^{-1}. Differences in individual probes did not bias sensor output for the variety of soils we tested, suggesting a standard calibration can be developed for any probe and then transferred to all other probes.

Figure 1 Comparison of volumetric water content with probe output for a single probe seven soil types, silty clay (SC), silt loam (SL-A and SL-B), silty clay loam (SCL), loam (L), sandy loam (SdL), and loamy sand (LS).

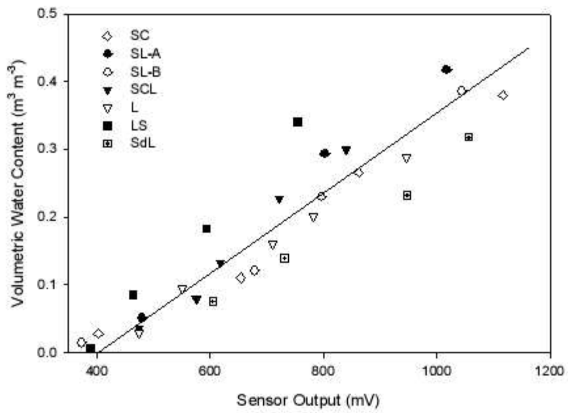


Figure 2 Linear regression of soils with low to moderate sand content. Regression R^2 was 0.94.

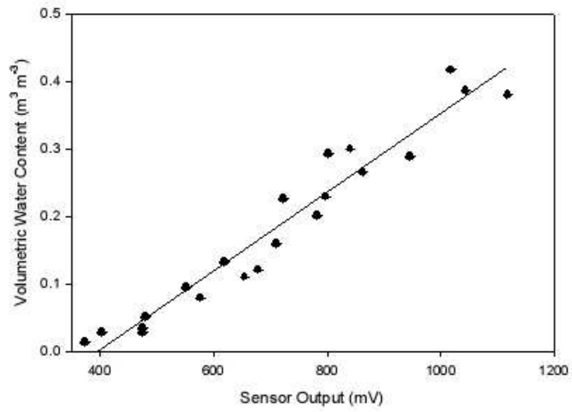


Figure 3 Sensor output for soils with high sand content. Line indicates overall calibration line for soils with low to moderate sand content.

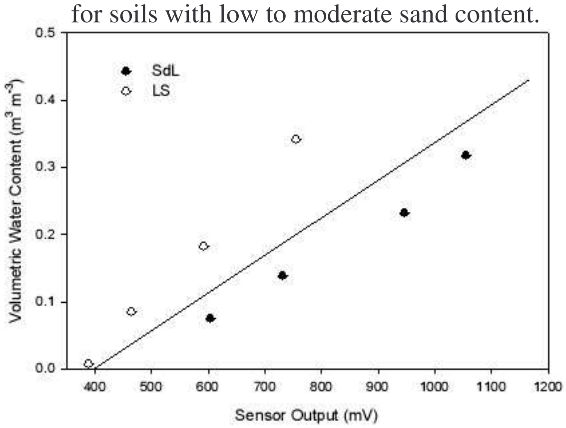
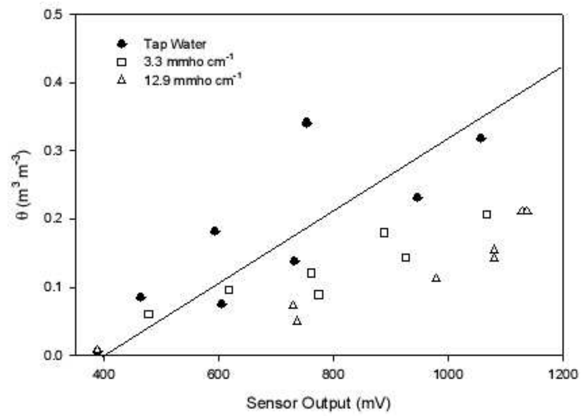


Figure 5 Calibration of sandy soils with increasing solution electrical conductivity.



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