AN INEXPENSIVE, PORTABLE METER FOR MEASURING SOIL MOISTURE

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Abstract

Until now, dielectric-based soil moisture measurements required expensive cable testers or commercial systems to read probes. Here we describe a method of constructing an inexpensive meter from a multimeter and a simple power supply. When coupled with a Campbell Scientific (Logan, UT) CS615 probe, the entire system costs ≈$350 US. A single meter can be used to measure multiple probes and the entire system is quite small and portable. The new system reads soil moisture probes capable of measuring a soil's dieclectric constant. Measurements taken with the meter described here and a CR10 data logger recommended by the probe manufacturer did not differ significantly. Nor was there any measurement offset between the data logger and the meter.

Time domain reflectometry (TDR) has proven to be a very effective means to infer in situ soil water content. Time domain reflectometry measures the velocity of electromagnetic pulses as they traverse a wave-guide of a known length inserted in the soil (Topp et al., 1980). The velocity of the signal changes with the dielectric constant of the soil, which is largely a function of the soil water content. Wave-guides are inexpensive and relatively easy to construct (Zegelin et al., 1989), however, measuring the EM pulse travel time requires an expensive cable tester.

The CS615 water content reflectometer (Campbell Scientific, Logan, UT) provides a less expensive means to measure soil moisture though changes in a soil's dieclectric constant. The CS615 probe consists of a small, portable, epoxy-encapsulated circuit board with two 30-cm steel wave-guides (Bilskie, 1997). The wave-guides are inserted into the soil, and the probe outputs a square wave with an amplitude of 2.5 volts direct current (V_{DC}). The probe is powered by 9 to 18 V_{DC} and is activated with a minimum 1.3-V_{DC} signal. Like TDR, the CS615 is sensitive to changes in signal propagation time along the wave-guide, driven by changes in a soil's dieclectric constant. The CS615 differs from TDR in that it uses a point on the signal reflected off the end of a wave-guide to trigger an event and generate output that varies in frequency, instead of analyzing the entire waveform as in TDR (J. Bilskie, 2000, personal communication). The output frequency (Hz) can be measured by a data logger, which inverts the output to give a period (milliseconds) and applies a polynomial function, converting the period to volumetric soil moisture content (Anonymous, 1996). Since soil dielectric measurements are influenced by soil physical and chemical properties such as texture (% clay and % organic matter) and pore water conductivity, the manufacturer recommends site-specific (or soil-specific) calibration of the probe. Campbell Scientific reported the probe accuracy as ± 2% soil volumetric water content when using a specific soil calibration.

Data loggers and other commercial soil moisture meters, while considerably less expensive than a cable tester, are still costly. Furthermore, when the user does not need to continuously log the probes or they are widely spaced, measuring them with a data logger monopolizes a versatile instrument that might be better used for other measurements if alternatives were available.

Here we describe the construction of a small, lightweight, and inexpensive meter for the Campbell CS615 water content reflectometer. We also compare the results of readings taken with our meter and a data logger recommended by the probe manufacturer.

Materials and Methods

The meter was built from a digital multimeter (Goldstar DM-332, LG Precision, Los Angeles, CA) capable of reading frequency, a 12-V_{DC} power source, a switch, and a 7805 5-V_{DC} voltage regulator integrated circuit (Fig. 1). Any multimeter capable of measuring frequencies in the range of 0 to 2 kHz could be used to construct the meter. For humid or wet environments, water-resistant multimeters are available. All of these parts are readily available off the shelf at a local electronics supplier. Eight 1.5 V AA batteries connected in series supplied the 12 V required to power the probe and the voltage regulator. The battery output was reduced to 5 V_{DC} by the voltage regulator that activates the CS615. A toggle switch was added to conserve battery power when the probe was not in use. The batteries and circuitry were enclosed in a small, hinged plastic box attached directly to the back of the multimeter, and the probe was connected using a five-conductor audio plug. The probes can be connected directly to the meter, or with connectors allowing repetitive reading of permanently installed probes.

This study compares the frequencies measured by our meter to a commercially available solid-state data logger (CR10, Campbell Scientific, Logan, UT). A CS615 probe was inserted, following the published procedures (Anonymous, 1996), in 15 scattered sites in oxic Humitropept soil at La Selva Biological Station, Costa Rica. The probe output was read with the meter and the data logger in random order at each site. The probe was enabled for 1 min before each reading to allow the probe output to stabilize. In order to put the frequencies into a more meaningful context, we applied an empirically-derived

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Abbreviations: TDR, time domain reflectometry; V_{DC}, volts direct current.

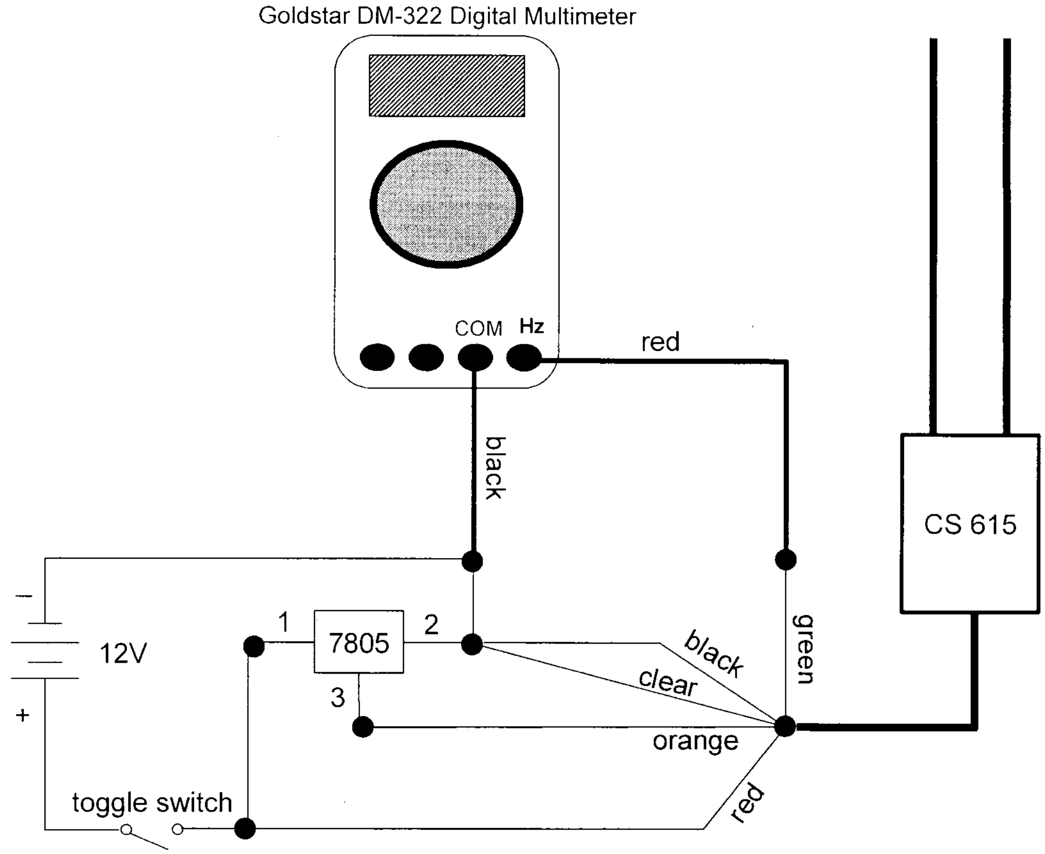

Fig. 1. Schematic diagram of the meter for the CS-615 probe. The pin numbers of the 7805 chip refer to (1) voltage in, (2) ground, and (3) voltage out.

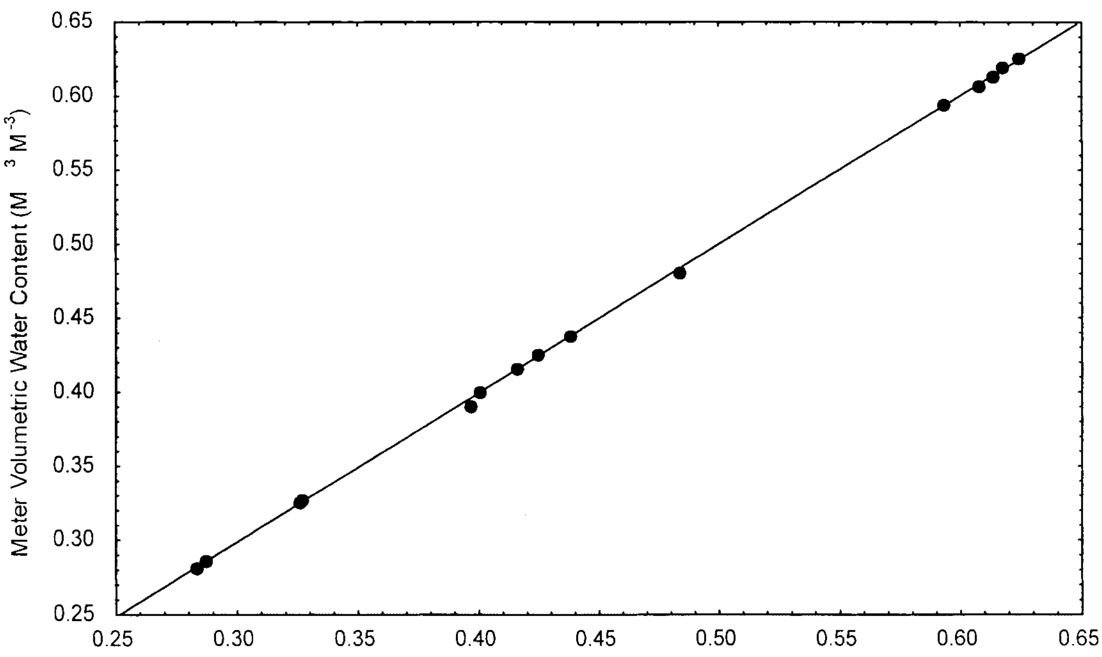

Fig. 2. Correlation between probe output measured with the CR10 data logger and the portable meter.

calibration to the frequency output (Veldkamp and O'Brien, 2000) to convert the probe output frequency to volumetric water content. This calibration function was used instead of the Campbell Scientific function because the soils at La Selva have high clay and organic matter content and low bulk densities.

Results

The CS615 drew 70 mA when activated, so AA batteries will last ≈21 h if the probes are read continuously, and much longer if intermittent readings are taken. The estimated mean soil volumetric water content values as measured by the meter (37.0%) and CR10 (37.4%) did not differ (t = 9.278, df = 14, P = 0.000). The values shown nearly perfectly correlated (R^2 = 0.9998, $F_{1,13}$ = 62987.61, P = 0.000) across the range of values we sampled, with a y intercept of 0 and a slope of 1 (Fig. 2).

Conclusion

The total cost for the complete system described in this paper, including a CS615 probe, is ≈$350 U.S. ($140 for the meter and $210 for the probe). In comparison, commercially available soil moisture meters or data loggers cost more than double this amount. Our meter has the added benefit of a smaller size and lighter weight than a data logger. The combined probe and meter weigh less than a kilogram, and can easily fit into a small backpack. Furthermore, we found no difference in the readings between a CR10 data logger and our probe.

We use the portable meter to measure soil moisture with CS615 probes installed in widely scattered plots in tropical rain forest. The meter and probes have performed well. Readings can be taken rapidly: with a five-conductor plug in place, the measurement takes ≈2 min, including 1 min to allow readings to stabilize.

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A SIMPLE FRACTURE MECHANICS APPROACH FOR ASSESSING DUCTILE CRACK GROWTH IN SOIL

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Abstract

The weak understanding of crack growth mechanisms in ductile soil is addressed by testing a new fracture mechanics approach. Samples are fractured using a deep-notch (3-point) bend test, with data on sample bending, crack growth, and crack mouth opening collected to assess the crack opening angle (COA), the crack tip opening angle (CTOA), and plastic energy dissipation rate (D_{pl}). The test variables are clay and salinity content, with samples formed from mixtures of kaolinite and fine sand. The CTOA and D_{pl} detect differences in fracture mechanics due to clay, but not salinity. The energy needed to drive crack extension, D_{pl}, is one order of magnitude higher for samples containing a ratio of sand to kaolinite of 75:25, as compared with 50:50. However, the CTOA due to plasticity was 0.19 and 0.24 for the same samples respectively, indicating that more strain is needed for crack growth in the specimens with more clay.

Modeling soil structure and its temporal nature could be improved significantly if the mechanics of crack development were included (Moran and Kirby, 2000). Research in this area, however, in comparison with other aspects of soil physical behavior, has been minimal despite its obvious significance as a basic physical characteristic of soil. Over the past decade, there has been a surge in pore structure modeling research (Perrier et al., 1995). Some of the investment in these studies, however, needs to be redirected so that soil structure modeling can be backed with a firm understanding of the origin of porosity through cracking.

Cracks originate in soil when the strain energy imposed by shrinking and swelling or tillage is sufficient to break interparticle bonds (Raats, 1984). Physically based models of soil cracking describe this phenomenon using techniques based on Griffith's (1920) pioneering work on the fracture mechanics of ideal linear elastic materials (Snyder and Miller, 1985; Lima and Grismer, 1994; Ayad et al., 1997). This approach describes the thermodynamic conditions required for catastrophic fracture. Evaluating the parameters needed for Griffith's theory is complicated for soil, hence most research has used the Irwin-Orowan extension to the model, which is stress rather than energy based (Lima and Grismer, 1994; Morris et al., 1992; Hallett et al., 1995). Either approach may be applicable to dry brittle soil, but they do not account sufficiently for plasticity in wet soil (Hallett, 1996). Like metals and other materials, plasticity can be a dominant sink to imposed strain en-

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Abbreviations: COA, crack opening angle over its entire length; COD, crack opening displacement at its mouth; CTOA, crack tip opening angle.