Soil Water Measurement with an Inexpensive Spectrophotometer[1]

S. A. Bowers, S. J. Smith, H. D. Fisher, and G. E. Miller[2]

ABSTRACT

A small, portable, battery-powered, spectrophotometer was developed to measure soil water content rapidly. Soil water contents of 16 soils were related to the absorbance at 1.94 μm by a soil-methanol extract by the curvilinear equation

$$\text{Absorbance} = K \left[\frac{\% \text{ soil water}}{100 + 1.025 \ (\% \text{ soil water})} \right] + a.$$

With the exception of Houston Black Clay, one equation could be used for all soils. Determination time for individual samples was approximately 15 min.

Additional Index Words: moisture measurement, absorbance.

RECENTLY Bowers and Smith (1) showed that soil water content can be measured by transmitting 1.94 μm through a methanol-soil extract. They proposed a rapid and accurate procedure; however, the required spectrophotometer was very expensive. The purpose of this investigation was to build an inexpensive spectrophotometer sufficiently sensitive to measure minute amounts of water. Construction of such an instrument seemed feasible, since Norris and Hart (3) had previously shown a relatively inexpensive spectrophotometer could be built to measure the water content of grain. Their procedure involved transmitting light through a ground grain-carbon tetrachloride paste or through intact grains.

INSTRUMENTATION

For wavelength selection an Optics Technology[3] interference filter was used. According to the filter transmittance calibration curve (Fig. 1), transmittance was maximum at 1.94 μm. The instrument was constructed so that filters could be changed when other wavelengths were required.

The light source, a Chicago Miniature Lamp Co. 20–6 card-reader lamp, was used with three simple double convex lenses (Fig. 2). The lenses and lamp were adjusted by trial and error so that a focal point was centered on a 0.04-mm pinhole stop. This blocked divergent rays and resulted in a paralleled beam through the liquid cell and a crisp circle of light focused on the detector. Focal lengths of lenses 1, 2, and 3 were 10, 18, and 18 mm, respectively.

The detection circuit (Fig. 3) consists of two unmatched lead sulfide detectors. Because of their temperature sensitivity the detectors were connected in a Wheatstone bridge so that changes in their resistance affected the bridge output in equal and opposite ways, cancelling one another out.

The light source was pulsed at 10 Hz by a transistor driver.

The signal to the driver was produced by an astable multivibrator operating at 10 Hz with 50% duty cycle. Since the magnitude of the AC signal from the bridge depends on the change in radiation striking the lead sulfide detector, thermal inertia of the incandescent light filament was an important consideration. To produce the maximum signal, the light should go from completely on to off. At pulsing frequencies above 10 Hz, the lamp filament failed to cool completely, thereby decreasing the output signal from the bridge. Current for the lamp, multivibrator, and driver is supplied by a rechargeable 6 V motorcycle wet-cell battery.

The AC signal from the bridge is coupled to a preamplifier through a capacitor which breaks any DC current loops, making the output independent of detector temperature changes. The preamplifier consists of an Analog Devices model 260J-hybrid, chopper-stabilized, amplifier operating at a gain of 1000. With no sample in the liquid cell, the amplifier output is 100 μA peak-to-peak. To eliminate induced 60 Hz components, the preamplifier signal passes through a 40 Hz cut-off, low-pass filter. The high output impedance of this filter is matched to the next stage of amplification by a National Semiconductor-type 741 monolithic operational amplifier operating as a voltage follower with unity gain. The follower output is again capacitively coupled to the third stage of amplification which is another type 741 operational amplifier. The last stage of amplification contains all the circuit gain adjusting and offset trimming potentiometers. The signal is sufficiently high so that small changes in operational amplifier characteristics do not contribute significantly to drift in the circuit. The output of this final stage is rectified by a bridge of four glass small-signal diodes. A 100-μA taut band meter (Simpson Model 524) is used to detect the DC output from the diode bridge. The rectifier output still contains appreciable 10-Hz ripple, which shows on the meter as needle bounce. Nevertheless, needle bounce was slight and did not preclude reproducible readings.

PROCEDURE

The experimental procedures were similar to those used by Bowers and Smith (1). For soil water extraction they used a ratio of 40 ml of anhydrous methanol/1 g of moist soil. Consequently, a series of eight standards was prepared by adding sufficient water to 250-ml aliquots of absolute methanol so that the resulting concentrations were equivalent to the extraction of water from 1-g soil samples each of 5, 10, 15, 20, 25, 30, 35, and 40% water by 40 ml of methanol.

Four surface soils (0 to 15 cm) were selected for testing: Amarillo fine sandy loam, Fort Collins clay loam, Grenada silt loam, and Houston Black clay. Several 50-g samples from each soil were selected and placed in individual cans. Water was then added to the samples to raise their water contents to predetermined levels. With each soil, water contents ranged from air dry to field capacity or higher.

All cans were sealed and samples were equilibrated for 3 weeks. Cans were turned daily to facilitate water distribution. At 3 weeks an approximately 2-g sample from each can was placed in a preweighed flask containing 50 ml of anhydrous methanol. The remainder of the sample was oven dried (24 hours at 105C) and water percentages were calculated. Based on increased flask weight, additional methanol was added to achieve a ratio of 40-ml/1 g of soil. All flasks were immediately stoppered, shaken vigorously for 5 min on a platform shaker, the extracts centrifuged, and the absorbances determined.

By definition the absorbance is

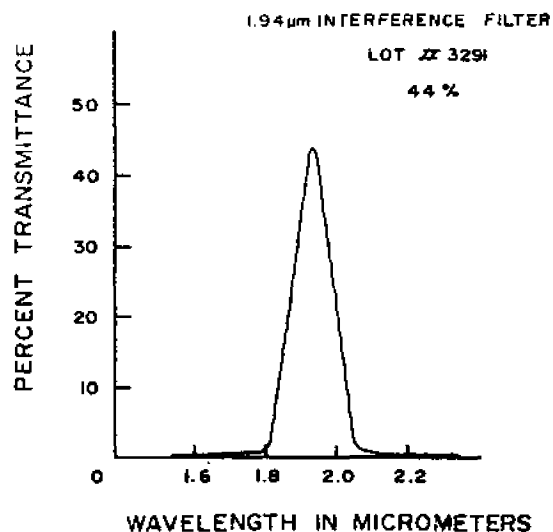$$A = \log_{10} I_o / I \qquad [1]$$

Fig. 1—Wavelength calibration curve for interference filter.

where

A = absorbance,
I_o = intensity of a monochromatic beam transmitted through pure solvent, and
I = intensity of a monochromatic beam transmitted through the solution.

I_o was obtained by placing a liquid cell containing absolute methanol in the light path and adjusting the gain until the meter read 100 μA. To determine I the absolute methanol was re-
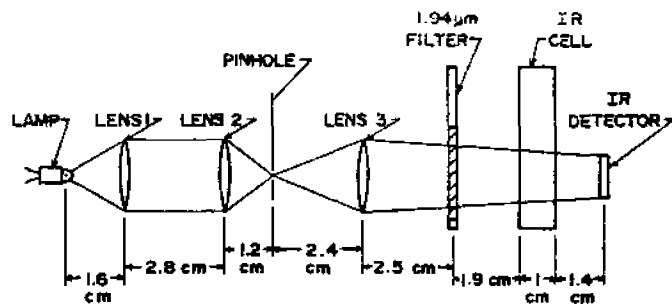
IR OPTICS SYSTEM

Fig. 2—Light and lens system for spectrophotometer.

placed by a soil-methanol extract and the arithmetic average of 10 consecutive needle positions calculated. Ten was an arbitrarily selected number; probably fewer readings would have sufficed. Absorbance was then calculated by Eq. [1] above. In addition, 12 other important agricultural soils were selected and two water contents randomly assigned to each; the maximum assigned water content was 48%. Samples were prepared as outlined above. However, at 3 weeks, samples with free water were discarded. The final soil water range covered was 2.0 to 35.0%. The 12 soils were Parshall fine sandy loam, Temvik silt loam, Sprole silt loam, Rago silt loam, Fargo clay loam, Webster clay loam, Caribou silt loam, Cecil sandy loam, Palouse silt loam, Aastad clay loam, Kranzburg silt loam, and Greenville clay loam. All except the last three soils were surface soils (0 to 15 cm); the remaining three were subsoils taken from a 60- to 75-cm depth.
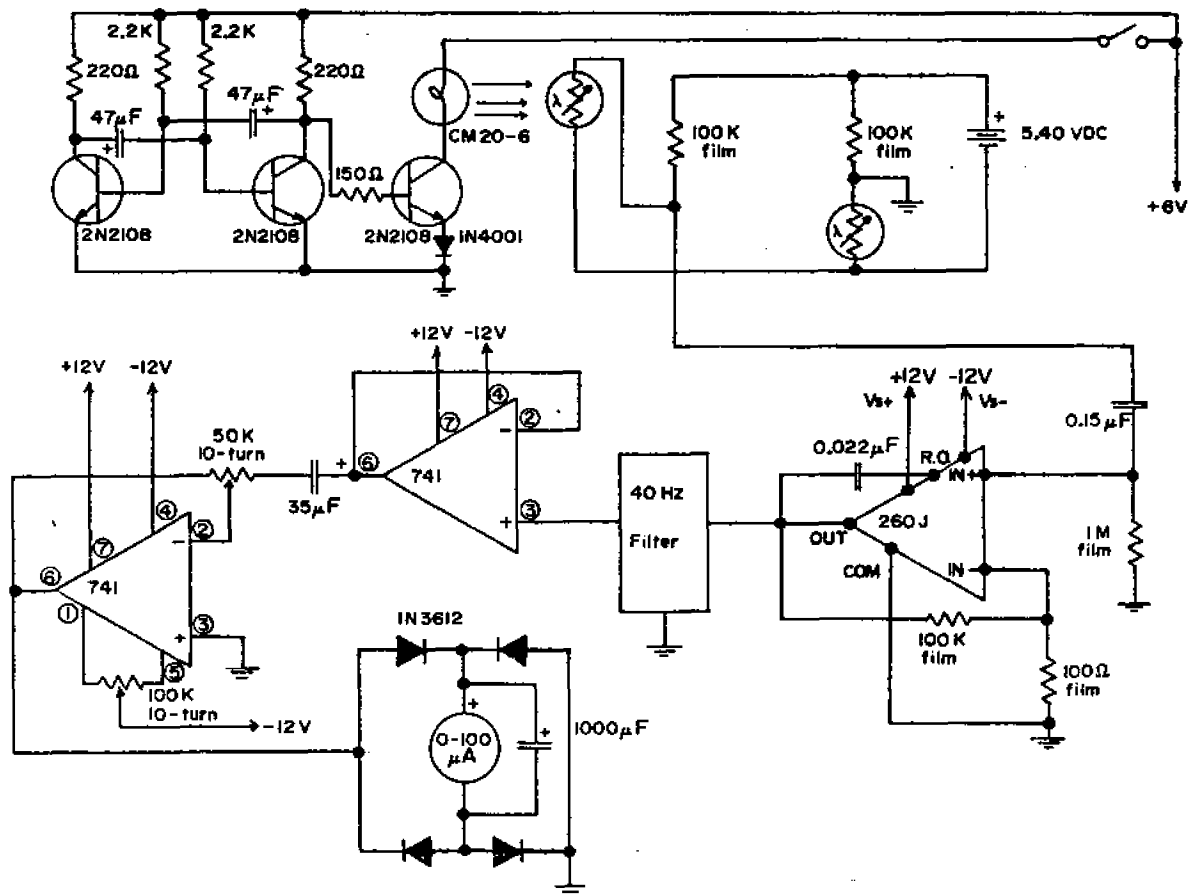

Fig. 3—Spectrophotometer circuit diagram.

Table 1—Regression data for absorbance at 1.94 μm vs. percent soil water (%W) where $W' = \%W/[100 + 1.025(\%W)]$

Soil	Regression equation	Standard deviation	r^2	CV
				%
Standard[a]	A=1.6418W'+0.0392	0.00721	0.99794	2.20287
Amarillo fine sandy loam	A=1.7895W'+0.0162	0.00647	0.99561	4.25649
Grenada silt loam	A=1.6645W'+0.0328	0.00580	0.99765	3.38436
Fort Collins clay loam	A=1.5522W'+0.0526	0.00804	0.99694	3.62335
Houston Black clay	A=1.2448W'+0.1144	0.01594	0.98379	5.03355
Pooled soils (12)	A=1.5980W'+0.0451	0.01002	0.99319	4.09865
All soils (15) except Houston Black clay	A=1.6351W'+0.0383	0.02450	0.99066	11.47756

[a] Water-methanol aliquots.

Bowers and Smith (1) had predicted that for the above extraction ratio the relationship between absorbance and percent soil water should be of the form

$$A = K\ \%W/[100 + 1.025\ (\%W)] + a \qquad [2]$$

where

A = absorbance,
%W = percent soil water on an oven dry basis, and
K = constant.

Therefore, regression equations of the form

$$A = KW' + a \qquad [3]$$

where

A = absorbance,
$W' = \%W/[100 + 1.025\ (\%W)]$.
K = regression coefficient, and
a = y axis intercept.

were determined for the standard, each of the four soils, and the pooled designated soils. In addition, the standard deviations $(s_{y.x})$, coefficients of determination (r^2), and coefficients of variation (CV) were calculated. Using analysis of covariance and a multiple comparison procedure (2), we tested the regression coefficients to determine which slopes differed significantly.

RESULTS AND DISCUSSION

Table 1 shows the regression equations, standard deviations, r^2, and CV. The results confirm predictions by Bowers and Smith (1) that a curvilinear relationship of the form of Eq. [2] exists between absorbance and percent soil water on an oven-dry basis. The high r^2 values (all more than 0.983) indicate not only an excellent relationship between absorbance and W' but also that from 98.4 (Houston Black clay) to 99.8% (Grenada silt loam) of the variation in absorbance was due to the variability in W' and hence to the variability in percent soil water. The analysis of covariance shows significant differences in regression coefficients $(F_{5,32} = 8.05**)$. When the multiple comparison procedure (2) was used, only the Houston Black clay regression coefficient was significantly lower (0.05 level) than those of the other soils and standard. This is similar to results previously reported (1) where Houston Black clay was compared with a loam and a loamy sand
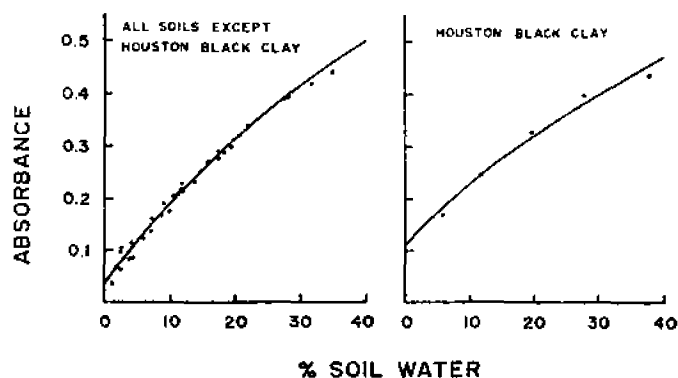

% SOIL WATER

Fig. 4—Absorbance vs. percent soil water (oven-dry basis) for Houston Black clay and all other referred to soils.

soil. Why the Houston Black clay regression coefficient differed from other soils is not known. However, the curve and data points for the five clay loam soils, i.e., Fort Collins, Aastad, Fargo, Webster, and Greenville, did not differ significantly from the standard.

The left half of Fig. 4 shows the standard curve with data points for all soils except Houston Black clay. The right half shows the Houston Black clay curve with associated data points. The fit of all points, except Houston Black clay, to the standard curve indicates that one calibration curve can probably be used for sand, loam, and clay loam soils. The regression equation for all soils, except Houston Black clay was $A = 1.6351W' + 0.0383$; the regression coefficient did not differ from that of the standard. The case for clay soils is less clear. Heavy-textured clay soil may require an individual calibration.

The instrument tested can measure soil water spectrophotometrically. The results show excellent correlation with oven-dry values; measurements are relatively rapid, requiring about 15 min. While the instrument has some disadvantage in needle bounce and a lack of precise zeroing capability (which results in a y-axis intercept), it is completely portable (dimensions = 25 by 15 by 15 cm; weight = 4 kg) and relatively inexpensive (total parts cost approximately $400).

LITERATURE CITED

1. Bowers, S. A., and S. J. Smith. 1972. Spectrophotometric determination of soil water content. Soil Sci. Soc. Am. Proc. 36:978–980.
2. Dunnett, C. W. 1955. A multiple comparison procedure for comparing several treatments with a control. J. Am. Stat. Ass. 50:1096–1121.
3. Norris, K. H. and J. R. Hart. 1965. Direct spectrophotometric determination of moisture content of grain and seeds. In P. N. Winn, Jr. (ed.) Principles and methods of measuring moisture in liquids and solids (Proceedings 1963 Int. Symp. on Humidity and Moisture 4:19–25.) Reinhold Publishing Corp., New York.