A New Tool for Fire Managers—An Electronic Duff Moisture Meter

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P rescribed fires are increasingly being used to reduce hazardous fuels, a major objective of the National Fire Plan. Despite advancing technology and ever-improving models, fire managers still find it challenging to determine the right time for a prescribed burn.

Measuring Duff Moisture Content

The effect of fire on the forest floor can vary from merely removing the litter to totally consuming the duff, which exposes the mineral soil and alters the surface soil structure. Fire managers often design prescribed fires to leave some of the duff to protect the mineral soil. Duff thickness and moisture content are the most important factors in determining duff consumption during fires.

In comparison to other woody fuels, duff has greater spatial and temporal variation in moisture content. Small precipitation events and heavy dew accumulations that have negligible effect on the moisture content of large fuels can significantly increase the moisture content of fine fuels and litter. And subsurface duff can lose moisture through evaporation much more quickly than the large woody fuels. Due to subtle differences in canopy

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closure, slope, aspect, and microtopography, duff moisture levels can vary significantly across the landscape, even at the hillslope scale.

These variations make it important to use real-time duff moisture measurements to estimate duff consumption and, more importantly, to achieve desired postfire duff depths. Using a measured duff moisture content in models like FOFEM (Keane and others 2003), fire managers can better estimate the duff remaining after a burn.

In the past, the fire manager might pick up a bit of duff, squeeze it firmly, and check the moisture before giving approval to begin the burn. The fire manager used past experience, weather information, and a "feel" for the current conditions as a final check.

An additional tool is now available. The DMM600,* a duff moisture meter (fig. 1), provides reliable, real-time measurements of duff moisture content. The DMM600 was patented and developed

through a cooperative research effort by three of the USDA Forest Service's research and development units—the Forestry Sciences Laboratory in Moscow, ID; and the Fire Sciences Laboratory and Missoula Technology and Development Center, both in Missoula, MT. The Forest Service collaborated with Campbell Scientific, Inc., in Logan, UT, for production and marketing.

How the Meter Works

The fire manager collects a sample from the portion of the duff layer just above the soil mineral horizon and pushes it through a #4 mesh sieve that fits in the opening of the sample chamber (fig. 2). Passing the duff through the sieve breaks

Figure 1—*The duff moisture meter (DMM600).*

up large organic fragments and removes sticks and rocks, allowing for more uniform packing.

After the sieved material fills the chamber, the cap is put on and the compression knob turned until an audible indicator signals that the sample is properly compressed (at 15 pound-force [66 N]). The meter then automatically takes the measurement and displays it at the base of the instrument. Readings are displayed in real time only; measurements are not stored. Total time needed to sieve and measure each sample is about 30 seconds.

The tough, lightweight DMM600 is a portable, battery-powered sensor that was developed from frequency domain reflectometry technology. When proper pressure triggers a measurement, a high-frequency signal of 42 MHz is applied to the sensor electrodes at the base of the sample chamber, and the sensor electronics detect the change in frequency of the reflected signal (fig. 3) (Robichaud and others 1999, 2000). The frequency change depends on the dielectric constant of the medium adjacent to the sensor electrodes. Because the dielectric constant of the medium varies with moisture content, the frequency change can be easily related, through a simple calibration function, to provide moisture content. The unit's microprocessor uses a factory-supplied calibration to convert the frequency to a volumetric moisture content and displays the value in the LCD readout.

Air voids in the duff can reduce the apparent dielectric constant and/or create a poor contact between the duff and the sensor electrodes. Using the meter's compression feature on sieved duff ensures that
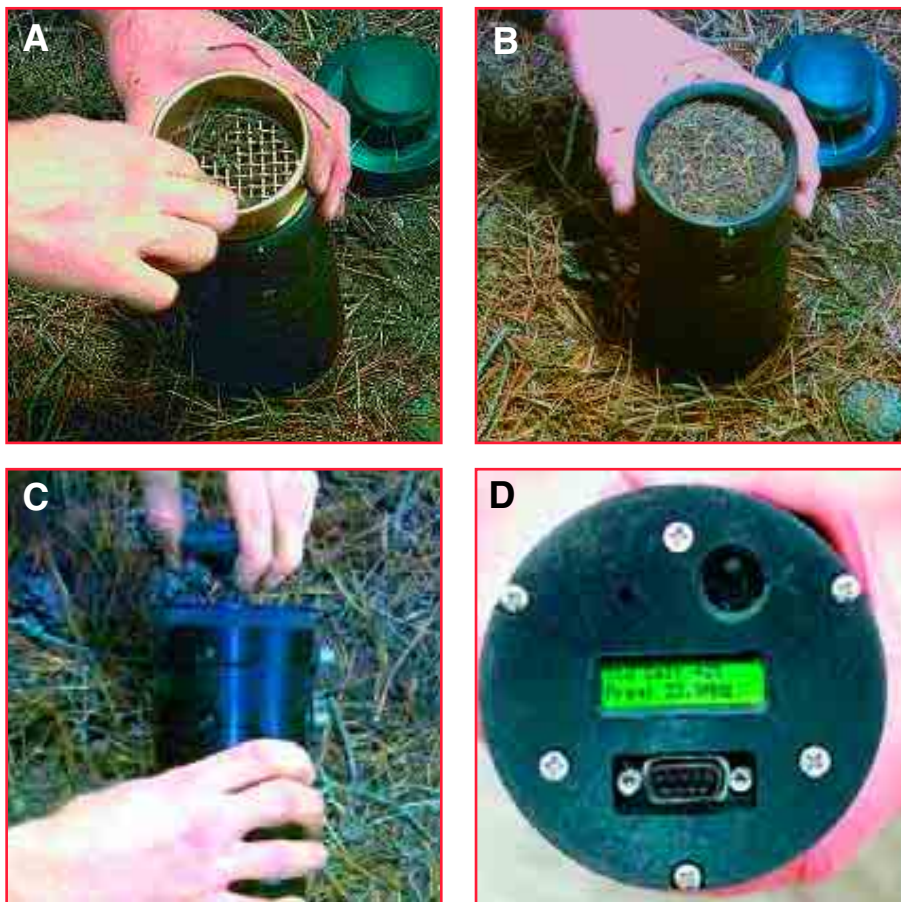
Figure 2—*Using the duff moisture meter in the field is simple and fast. Toggle the power switch on and select the duff to be sampled—usually from the lower half of the duff layer. (a) Push the duff sample through the sieve into the chamber. (b) Fill the chamber with the duff. (c) Compress the sample using the hand-turn knob, stopping when the audible signal is sounded. (d) Read the moisture content from the display window at the base of the instrument.*

each sample is pressed evenly against the sensor electrodes, which reduces measurement variability.

Calibration

The factory-supplied calibration for the DMM600 is derived from laboratory measurements of the volumetric moisture content of duff from eight different forested sites. Depending on elevation, the cover species included Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*), western larch (*Larix occidentalis*), ponderosa pine (*Pinus ponderosa*), and Douglas-fir (*Pseudotsuga menziesii*). Because

Figure 3—*The bottom of the sample chamber is a printed circuitboard containing two interlocking finger sensor electrodes attached to a movable piston.*

Specifications

Physical

Dimensions:	3.5 inch (9 cm) diameter
	10 inch (25 cm) length
Weight:	3.7 lbs. (1.7 kg)
Sieve:	#4 mesh = 0.203 inch (5.16 mm)
	3 inch (7.6 cm) diameter

Power

Battery:	9 V alkaline
Measurements per battery:	> 2000

Performance

Accuracy:	± 5 percent for full scale range
Resolution:	1 percent volumetric moisture content

Included with the DMM600:
- CD containing (a) video instruction, (b) PCDMM software, (c) DMM600 Instruction Manual, and (d) Excel spreadsheet for calibrations.
- 6-foot (1.8-m), 9-pin serial cable.
- Soft-sided, padded carrying case with screwdriver and spare 9-volt battery.

the individual calibration curves were similar, the data were combined to develop a single, standard calibration curve (fig.4).

The error bars indicate that measurement accuracy decreases as moisture content increases. The accuracy is approximately ±4.0 per-
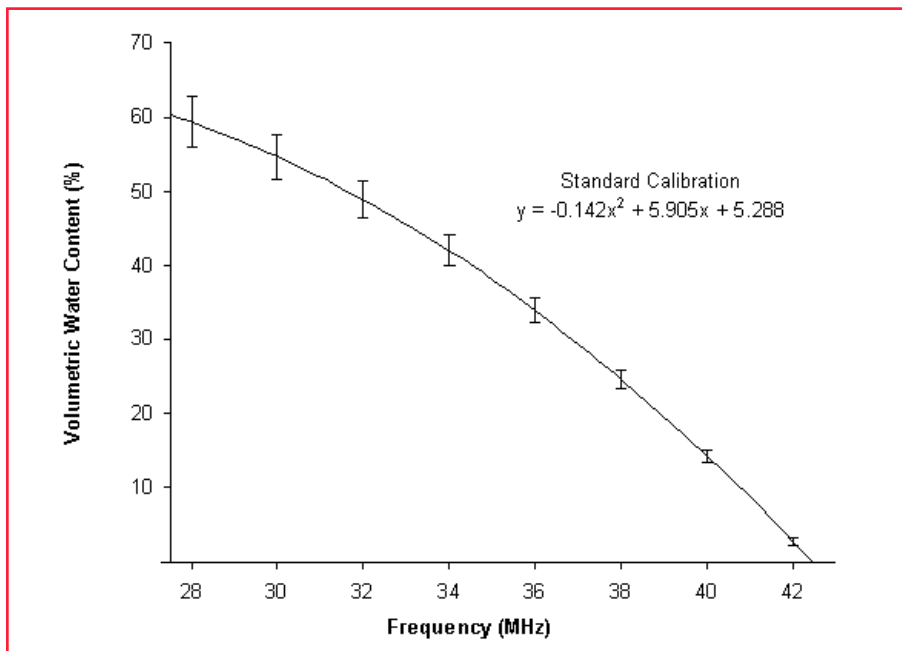

Figure 4—*DMM600 standard calibration curve. The variability is smallest in the lower moisture/higher frequency area of the curve, where accuracy is most critical.*

The standard calibration curve will likely meet the needs of most fire managers across a range of vegetation types.

cent at 60 percent volumetric moisture content and approximately ±1.5 percent at 30 percent volumetric moisture content. It is recommended that the average of samples from several nearby locations be used to reduce the effects of natural variability.

The meter's response to changing moisture content is best described with a quadratic calibration equation:

Volumetric Water Content =
$5.288 + 5.905 \times freq - 0.142 \times freq^2$,

where *freq* is the DMM600 readout frequency in MHz. User-derived calibrations can be determined using the laboratory procedures described in the *DMM600 Instruction Manual* and the *DMM600 calibration spreadsheet.xls* provided in the PCDMM software package (Campbell Scientific 2000). User-defined calibrations are entered into the PCDMM interface and loaded to the DMM600 through a serial port connection.

Studies done on eastern hardwood duff from Massachusetts show little deviation from the standard calibration curve. It is likely that the standard calibration curve will meet the needs of most fire managers across a range of vegetation types.

Gravimetric Moisture Content

The basic operation of the DMM600 gives the volumetric moisture content of the sampled duff. Using a simple calibration process, the gravimetric ("dry-weight-based") moisture content—the measurement most commonly used by fire managers—can be added to the instrument readout.

A value for duff bulk density is needed for this calibration process. Fire managers may choose to use a known bulk density value or determine one from local conditions (*bulk density = dry weight ÷ volume*). Each coefficient in the standard calibration equation is divided by the bulk density. The three gravimetric coefficients are entered into the PCDMM software (fig. 5)

Figure 5—*The PCDMM duff moisture meter interface software. A user-defined calibration curve, such as for gravimetric moisture content, can be added by setting the three calibration coefficients. The DMM600 display alternates between the standard volumetric moisture content and the user-defined calibration for each measurement.*

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and uploaded to the DMM600 through a serial port connection on the base.

Because duff bulk density is relatively constant, this calibration process can be completed before going to the field to make duff moisture measurements. When each field measurement is made, both the standard volumetric moisture content and the user-defined gravimetric moisture content are alternately displayed in the readout.

Critical Information

Duff moisture content is critical information for fire managers making operational and planning decisions for prescribed burns. The DMM600 provides dependable duff moisture content data, both in the field and for input in predictive modeling programs. For more information, contact Pete Robichaud at the Forestry Sciences Laboratory, Rocky Mountain Research Station, 1221 S. Main St., Moscow, ID 83843, tel. 208-883-2349, email: <probichaud@fs.fed.us>.

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