The GLOBE Soil Moisture Campaign's Light Bulb Oven: Successful Results for 4 Soil Types

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Introduction

GLOBE (Global Learning and Observation to Benefit the Environment) is a worldwide, hands-on, primary and secondary school-based science and education program. Partially funded by NASA, the National Science Foundation, the University Corporation for Atmospheric Research (UCAR) and Colorado State University (CSU) have created a partnership to manage the GLOBE Program. GLOBE is a cooperative effort of schools, federal agencies, universities, and non-governmental organizations in partnership with 105 countries worldwide. The GLOBE Soil Moisture Project is a subset of the overall program, and aims to recruit and mobilize GLOBE-participating students worldwide to collect near-surface (i.e. 0-5 cm and 8-12 cm) gravimetric soil moisture data twice a year. The selected annual target dates are during World Space Week/U.S Earth Science Week (mid-October) and Earth Day Week (mid-April).

One of the goals of GLOBE has been for students to collect quality data that can be used by professional scientists in their research. A major challenge for the SMC was to develop a method for collecting soil moisture data that would meet the quality standards required for scientific data, but at a price and level of simplicity suitable for widespread, worldwide school participation.

Methods for Determining Soil Moisture

Several options for soil moisture sampling were considered. First, standard methods were reviewed. Eleven different standard methods are discussed by Topp and Ferré (2002). They include: 1) thermogravimetric method using convective oven-drying; 2) gravimetric method using microwave oven-drying; 3) time-domain reflectometry; 4) ground penetrating radar; 5) capacitance devices; 6) radar scatterometry or active microwave; 7) passive microwave; 8) electromagnetic induction; 9) neutron thermalization; 10) nuclear magnetic resonance; and 11) gamma ray attenuation. Of these eleven, only the first two methods seemed appropriate and economically viable for schools.

While gravimetric soil moisture sampling is a relatively elementary exercise that can be collected by students of almost any age, one of the central challenges to achieving a successful student-collected soil moisture data set has been identifying a reliable, low-cost means to dry soil samples. Most K-12 schools do not own a laboratory oven because the cost of purchasing a traditional laboratory oven is prohibitive. Even a small, low-end lab oven costs at least $325, which exceeds the annual equipment budget of many science classrooms in the United States, let alone developing nations worldwide.

The use of microwave and conventional gas/electric home-use ovens to dry samples offers some benefits: they are widely available in the United States, and they are easy to use. However, they are not the most viable option for drying soil samples for several reasons. First, it is important to avoid overheating the soil, because water molecules that are integral to clay minerals could burn off and subsequently decrease the dry mass of a soil sample, thus contributing to an erroneous calculation of gravimetric soil moisture. A microwave-dried soil sample runs the risk of overheating if the soil is dried for too long. Overheating can also occur in a conventional oven, which is sometimes difficult to regulate consistently. Second, the heating of some soil samples tends to be accompanied by strong organic odors that are not particularly appetizing, yet tend to linger in conventional ovens and especially in microwave ovens. Accordingly, we do not recommend that teachers dry their students' soil samples in the microwave in the teacher's lounge, or in the conventional ovens in the home economics classrooms, or any other ovens that are used regularly to heat food. Finally, even if one were to own a "spare" microwave designated for laboratory use, it would take a prohibitively long time to dry a large number of students' soil samples, one at a time. Our concern is that students would become bored and disengaged, or might try to rush the process by drying the soil for longer periods of time, resulting in overheating the sample and an erroneous soil moisture calculation. Despite these drawbacks, the GLOBE SMC supports a soil moisture data collection protocol that includes microwave drying; however, the challenge remained to develop a more widely-accessible drying method.

An assessment of non-traditional methods for measuring soil moisture identified two possibilities. One is a variation on the gravimetric method, in which the soil is air dried and then placed in a sealed chamber with a saturated salt solution that controls the chamber's humidity (O'Brien, 1948). Another method is called the rapid immersion method (Leite et al. 1994). However, while generally meeting the criteria of low-budget and low-technology, these methods are not practical for K-12 teachers and students. In particular, each requires a calibration sample of oven-dry soil, which obviously requires an oven. We thus remain with the initial problem of the general lack of availability of appropriate and affordable ovens for K-12 teachers. For a detailed description of non-traditional methods see Whitaker et al. (2004, submitted).

The suggestion of air-drying soil samples was also considered, but dismissed, as different parts of the world experience vast differences in relative humidity, and it would be difficult to prescribe a consistent methodology.

The Development of a Low-Budget, Low-Technology Oven

Given the relative simplicity of collecting gravimetric soil samples, we reconsidered the thermogravimetric method using convective oven-drying. Instead of relying upon a standard, relatively expensive oven, however, we decided to design and construct a low-budget, low-technology oven for drying soil samples. Once the test oven was built, we have 1) compared the new oven with a traditional laboratory oven's ability to achieve a steady target temperature of 100-110 °C; 2) compared the new oven with a traditional laboratory oven's ability to dry soil samples, using a variety of soil types, including a clay-rich and an organic-rich soil; and 3) publicized the new oven's design schematics, construction instructions, and the estimated cost and savings.

The new, low-budget, low-technology design for drying soil samples is called the "light-bulb" oven. The "oven" is constructed from a 55-gallon drum, cut in half lengthwise, covered with aluminum-backed fiberglass insulation, and placed on a ring of flat cement bricks. The oven uses the heat from four 100-watt light bulbs (see Figure 1). A glass thermometer placed in the oven allows for manual temperature readings, and a gap in the ring of concrete bricks provides a vent for air circulation and temperature control. Adjusting the size of the air gap allows the user to regulate the oven temperature to a steady temperature near 105 ^{o}C. A detailed list of the materials required for building the oven are shown in Table 1. While specific sizes are listed for the concrete bricks, it is certainly possible to vary the sizes, as long as the purpose is met of elevating the oven to create an opening for temperature control. The bricks also contribute thermal mass and offer protection to the surface on which the oven is placed.

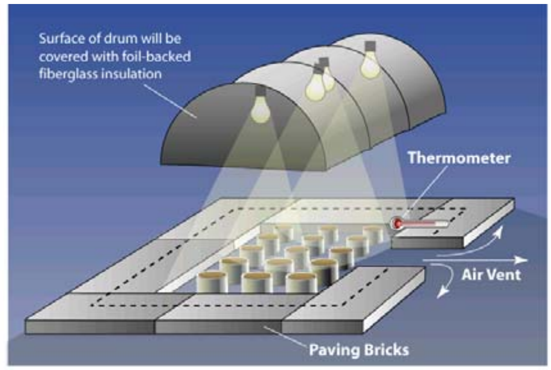

Figure 1. Schematic of the light bulb oven.

The total cost of the light bulb oven is $100 USD or as little as $75 USD if two groups split the cost of a 55-gal drum (only ½ drum is needed per oven). Given that the cost of a low-end, laboratory convection oven is $325 USD, the potential savings is $225 - $250, which translates to a 70-77% savings.

Table 1. Materials required for the construction and use of a light bulb oven
One 55-gallon drum, cut in half
Eight 8x2x16" concrete bricks
One 20 x 10 x 5.5 cm brick
Heavy-gage, insulated lamp wire and three plugs
Three light bulb socket with push-through switch
One Thermometer [>105 C];
Two (12"x2"x15') rolls of aluminum-backed fiberglass duct insulation (R factor = 6)
One Twin light bulb socket
Two rolls of Al-backed tape, rated to function at temperatures at least 110 °C (2"x 40yds)
Four 100-watt light bulbs
Miscellaneous nuts & bolts

Methods

The light bulb oven was initially tested solely on its ability to achieve the same uniform internal temperature pattern as a traditional laboratory convection oven. Nine thermocouples were placed on a 3 x 3 grid in the center of the light bulb oven and on the center rack of a standard drying oven (Yamato DX-400). A data logger was used to record temperatures in the ovens at 15 minute intervals for over 24-hours, which corresponds to the standard length of time specified for drying soil samples for gravimetric analysis (Topp and Ferré, 2002). For this initial experiment, there were no soil samples present and there was no air gap between the concrete blocks.

A subsequent experiment was designed to show that samples of different soil types, comprised of varying amounts of clay, would dry with the same quality and repeatability in the light bulb oven as in a traditional laboratory oven. Four soil types were used to test the ability of the light bulb oven to replicate the quality of soil drying from a traditional lab oven. Local Pima, Gila, and Sonora soils were selected based on their varying clay content. One concern was that soils with a higher clay content might not dry as readily in the light bulb oven, or might raise the humidity in the oven and thus inhibit effective drying. The Pima soil had the highest percent of clay (38.0%). An additional concern was that the light bulb oven, by nature of generating light, might affect highly organic soils. To test this possibility, we included a sample of composted soil with a high organic content. The soil texture of all four soils is plotted on the textural triangle in Figure 2. Each soil was uniformly wetted in the laboratory and twelve samples of each soil were placed in both the light bulb and traditional laboratory ovens for the same amount of time, 24 to 48 hrs, which corresponds to accepted standard methods (Topp and Ferré, 2002)

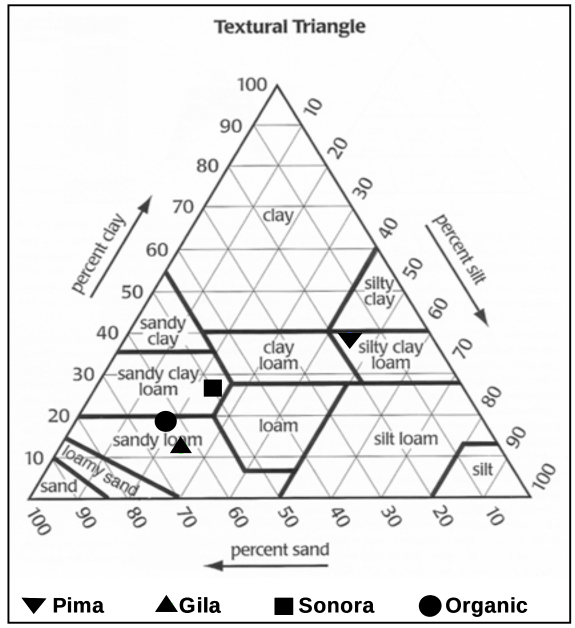

Figure 2. Soil texture triangle with plot of soils used to test light bulb oven.

Results

For the initial experiment, in which the light bulb oven was compared solely on the basis of temperature, the data show that the light bulb oven heats gradually, achieving a constant temperature in approximately twelve hours (see Figure 3). A constant temperature of 105 ^{o}C can be achieved simply by varying the size of the air gap in the front of the oven. In the oven design we used, the placement of a concrete brick in front of the air gap served to refine the oven temperature. In contrast, the convection oven achieved the target temperature of 105 ^{o}C within one hour, but then the

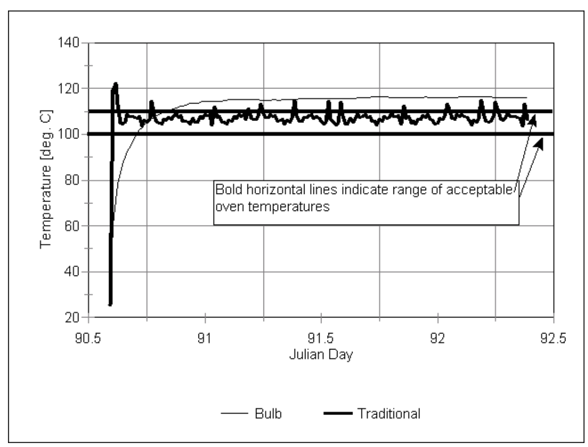

Figure 3. Comparison of average temperatures over time in the light bulb and traditional ovens. Subsequent experimentation has shown that the oven temperature can be adjusted by varying the size of the air gap

temperature oscillated by as much 8 ^{o}C (Figure 4). Although the temperature in the traditional oven frequently exceeded 105 ^{o}C, the average temperature was ~107 ^{o}C, well within the desired range of 100-110 ^{o}C.

Results for the four soils (Figure 4) demonstrate that the light-bulb oven successfully dries soil samples with the same accuracy as a traditional laboratory oven. The light-bulb oven yielded excellent results even for: 1) the clay-rich Pima soil (38% clay), which held more water than the other test soils; and 2) the organic-rich compost. The root mean square error (RMSE) was impressively low: 0.0009.

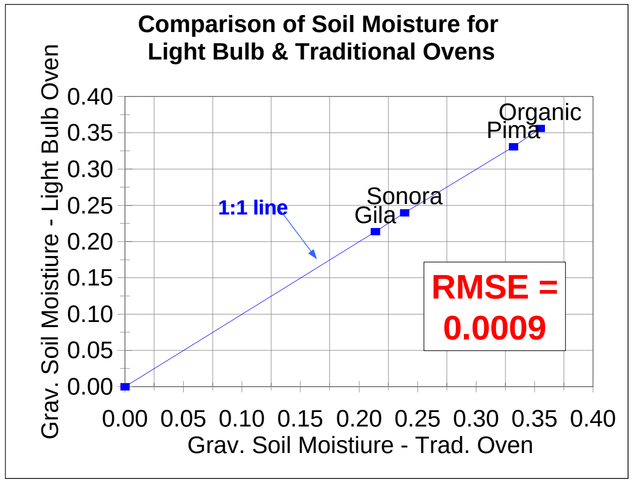

Figure 4. Comparison of results of four soil types dried in the light bulb and traditional ovens.

Conclusions

An inexpensive light bulb oven was shown to achieve a constant temperature within the desired range of 100-110 °C. The light bulb oven required longer to achieve a constant temperature than a convection oven, but did not show the temperature oscillations seen in this standard equipment. The cost of the light bulb oven is less than 33% that of a low-end traditional convection oven. For comparison, the light bulb oven cost was 7% that of the convection oven used in this experiment. Both the light bulb oven and low-end convection oven can hold approximately 75 8-cm diameter soil sample cans. Based on these results, the light bulb oven shows promise as a low-budget, low-technology method to measure gravimetric soil moisture. This will allow for the extension of the GLOBE Soil Moisture project into schools with limited financial resources.

The light bulb oven's design detailed schematics, construction instructions, and the estimated cost and savings are available at http://www.hwr.arizona.edu/globe/sci/SM/SMC/

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