

Development of Mini-Gypsum Blocks for Soil Moisture Measurement and their Calibration to Compensate for Temperature

A. Keyhani¹

ABSTRACT

To measure soil water content (or soil matric suction) in thin layers of about 30mm, conventional gypsum blocks are not suitable. To carry out the task, mini-gypsum blocks were constructed using plaster of Paris in an innovative fashion. A power relationship was found between the soil water content and the mini-gypsum blocks' readings in $k\Omega$. The calibration results showed that readings of mini-gypsum blocks were sensitive to temperature. A normalized resistance deviation method was adopted to compensate for the effect of temperature on the sensor readings. After calibration, the high coefficient of determination obtained ensured the use of the mini-gypsum blocks for further experiments.

Keywords: Matric suction, Normalized resistance deviation, Plaster of Paris, Temperature calibration, Water content.

INTRODUCTION

Gypsum blocks are used to measure the water content of soil (actually soil matric suction) or any other porous media alike. Its ability to absorb water and to come into equilibrium with the medium makes it a convenient sensor by measuring electrical resistance, especially in continuous readings along with data-loggers (Hillel, 1982). Gypsum blocks are cheap, simple in design and structure and can be used without disturbing the soil media. Conventional gypsum blocks are usually of large dimensions, making them inappropriate for use in some experiments. For instance, monitoring the water content of different thin layers of a column of soil (about 30 mm) by conventional gypsum blocks is impossible. Another limitation in using this type of sensor is the temperature dependence of readings (Hillel, 1982). In this paper, all stages of developing and calibrating the innovative mini-gypsum blocks to be capable of measuring soil mois-

ture in thin layers are reported (Keyhani, 1997).

MATERIALS AND METHODS

Mini-gypsum blocks were constructed using a clear acrylic mold capable of making four blocks at a time and prepared in four layers (57 mm $\times$ 160 mm) in the Engineering Shops at the University of Saskatchewan. The base layer (6 mm thick) was solid and each of the other three layers (3 mm thick) had four openings of the dimensions 3 $\times$ 15 $\times$ 17 mm (Fig. 1).

For each gypsum block, two probes of stainless steel mesh screen No. 14 (0.64 mm) with the dimensions of 10 $\times$ 10 mm were used. The first layer of the mold with openings was placed on the base layer and secured with pins at all four corners. A mixture of plaster of Paris (gypsum) and distilled water in a ratio of 10g plaster of Paris to 7mL of distilled water was prepared and

¹ Department of Power and Machinery, Faculty of Agriculture, University of Tehran, Karaj, Islamic Republic of Iran.

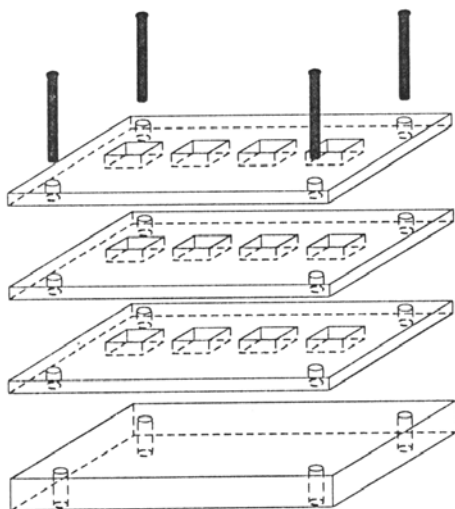


Figure 1. Schematic diagram of the acrylic mold.

then poured into the openings. After approximately two minutes to allow the mixture partially to set, the first probe for each block was placed and positioned in the middle of each opening. After placing the second layer on top of the first one, the openings were again filled with the mixture and allowed to set for two minutes. The last layer was then put in place and the second probe for each block was positioned in the middle of the opening. The openings were filled with the mixture and allowed to set for 40 minutes. Gypsum blocks of $9 \times 15 \times 17$ mm were pushed out from the mold and placed in distilled water for 24 hours to gain further strength and thus complete the setting process.

Mini-gypsum blocks were calibrated for both water content and temperature. Toth and Maulé (1993) have presented a method to calibrate a probe-type sensor for measuring soil electrical resistance, in which the temperature effect was also taken into account. A similar procedure was followed in this study.

For calibration, mini-gypsum blocks were embedded into clay soil samples in small sealed plastic containers. The gravimetric water contents used for the soil varied from approximately 16% to 37%. The mini-gypsum blocks were allowed to equilibrate

with the media for 24 hours, then the containers were placed in a controlled environment in the Phytotron facility of the University of Saskatchewan. The temperature was changed every eight hours from 5°C to 15°C in increments of 5°C over a period of 24 hours. These temperature settings were chosen according to the local meteorological data representing the time of seeding which is usually in early May for a typical grain crop in Saskatoon (Wittrock and Wheaton, 1991; Environment Canada, 1991).

Sensors were hooked up to the Campbell CR-21X data-logger and the sensor resistances were stored in a computer for further analysis. The small size of the cylindrical containers (60 mm height $\times$ 80 mm diameter) and the relatively long period of time allowed for each temperature setting ensured temperature equilibrium throughout each container within each 8-hour setting.

Due to the perishable nature of the mini-gypsum blocks and possible destruction during calibration and during the main experiment (which happened for four of the gypsum blocks), 42 sensors were made and calibrated.

RESULTS AND DISCUSSION

The water content-resistance showed the power (logarithmic) relationship as:

$$WC = 100 aR^b \quad (1)$$

where WC is the gravimetric water content as a %, R is the resistance in $\text{k}\Omega$, and a and b are curve fitting parameters. As an example, the following equation was obtained for one of the sensors at 15°C :

$$WC = 36.1R_{15}^{-0.156} \quad (R^2 = 0.998) \quad (2)$$

where R_{15} is the reference resistance at 15°C in $\text{k}\Omega$.

Equation 1 was found to be temperature-dependent. Figure 2 shows the dependency of the soil resistance on temperature for the same sensor in a semi-log scale. To eliminate the effect of temperature, the variable Y is defined as normalized resistance deviation

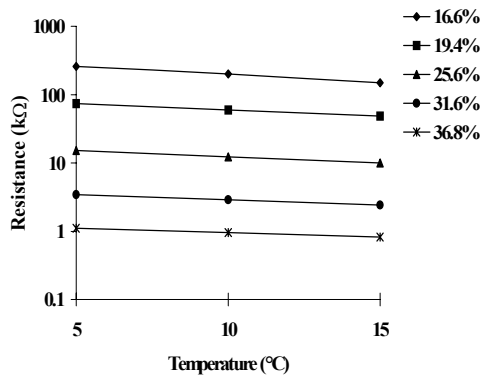


Figure 2. Temperature effect on soil resistance readings with the different water contents of 16.6%, 19.4%, 25.6%, 31.6% and 36.8%.

from a reference resistance (in this case 15°C):

$$Y = \frac{R_k - R_{15}}{R_{15}} \quad (3)$$

where Y is the normalized resistance deviation in $k\Omega/k\Omega$ and R_k is the soil resistance in $k\Omega$. Figure 2 is now transformed into Figure 3 in which the variations in both temperature and water content are reflected in the graphs.

Using a multiple linear regression analysis on the same sensor readings versus normalized resistance deviation and temperature, the following relationship was found:

$$Y = 0.0009 R_k - 0.049 T + 0.681 \quad (4)$$

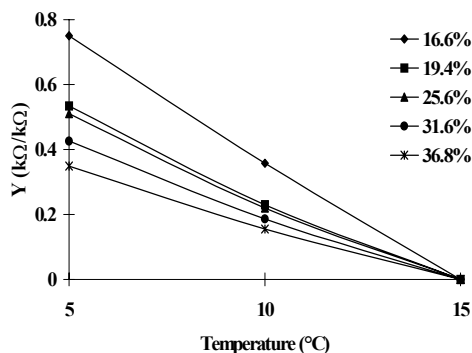


Figure 3. Variation of normalized resistance deviation with temperature at the different water contents of 16.6%, 19.4%, 25.6%, 31.6% and 36.8%.

$$(R^2 = 0.956)$$

By integrating equation 4 into Equation 3 solving the value for R_{15} and then integrating it into Equation 2 the following final calibration equation for the mini-gypsum block is derived:

$$WC = 36.1 \left(\frac{R_k}{0.0009R_k - 0.049T + 1.68} \right)^{-0.156} \quad (5)$$

where T is temperature in °C. Equation 5 predicts the water content for that specific mini-gypsum block provided that the soil resistance and the temperature are known. The same procedure was followed for calibrating the other mini-gypsum blocks. From the 42 sensors made, those with the highest coefficients of determination were selected to be used in monitoring the soil moisture in thin layers in any further experiments.

During the calibration of mini-gypsum blocks, it was found that in low gravimetric water contents (less than approximately 15% for the soil used) the readings were unstable and exceeded the resolution of the data acquisition system. Toth and Maulé (1993) also reported the same problem in low water contents.

The developed mini-gypsum blocks were used along with thermocouples in an experiment to monitor the variation of water content and temperature of a clay soil column at the different depths of 15 mm, 45 mm, 75 mm and 135 mm while undergoing a drying process under a cyclic temperature (15 °C for 16 hours and 5 °C for 8 hours) for a week (Fig. 4).

For part of the experiment, the dry bulk density was 1.15 Mg/m³ and the initial water content was 32%. The same data logger as in the calibration procedure was used to collect data. The only way to check the accuracy of the collected data was to compare the equivalent water content of the final readings of the mini-gypsum blocks corrected for temperature with that of the oven method for the soil samples of the same depth (Table 1).

The results given in Table 1 clearly show the ability of mini-gypsum blocks for predicting the water content of soil layers at

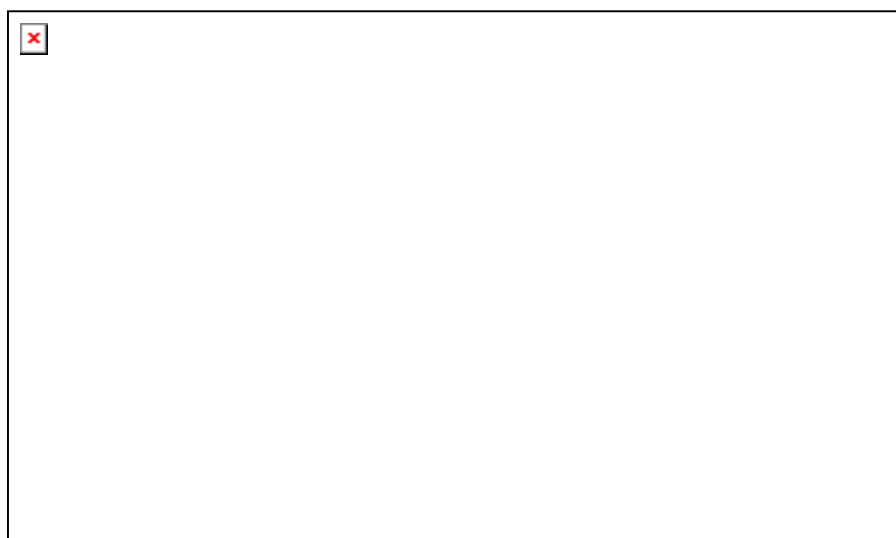


Figure 4. Schematic diagram of the experimental setup.
T and RH represent temperature and relative humidity, respectively.

Table 1. Comparison of the equivalent gravimetric water content of mini-gypsum blocks with the oven method.

Depth (mm)	Gravimetric water content (%)			Absolute error (%)
	Mini-gypsum block	Oven method ^d		
		Mean	S.D.	
15	16.8	17.9	1.51	6.55
45	27.0	26.2	1.01	2.96
75	29.2	28.5	0.839	2.46
135	31.9	31.2	0.503	2.57

^a With three replicates

different depths with sufficient precision. The relatively high percentage of absolute error at a depth of 15 mm was due to the deep cracks formed during the drying process of the top soil layer down to the mini-gypsum block sensor. The relatively higher standard deviation at a depth of 15 mm for the oven method justifies the higher absolute error corresponding to that layer owing to the cracks.

CONCLUSION

Conventional gypsum blocks are not suitable for monitoring the water content of thin layers of soil. A mixture of 10g plaster of Paris with 7mL of distilled water and two probes of stainless steel mesh screen No. 14

were used as basic materials to construct the mini-gypsum blocks used here. The method presented in this article to develop and calibrate mini-gypsum blocks of 9×15×17 mm to carry out the task, was completely satisfactory. The temperature dependence of the blocks' readings was taken into account during the calibration procedure. The water content and resistance showed a logarithmic relationship with each other. The high coefficient of determinations obtained (> 0.95) ensured the use of the mini-gypsum blocks with a high level of confidence. The resolution of the data acquisition system was a limiting factor in calibrating the gypsum blocks in lower soil suctions corresponding to lower gravimetric water contents. In this study, for the clay type soil used, gravimetric water contents of lower than 15% pre-

sented unstable and erroneous results.

This much is certain mainly when the results are considered in the context of the materials, methods and conditions adopted in this study and any generalization should be viewed with caution.

REFERENCES

1. Environment Canada. 1991. Canadian Climate Normals. Prairie Provinces. 1961-90. *Environment Canada*. A publication of the climate program.
2. Hillel, D. 1982. *Introduction to Soil Physics*. San Diego, CA: Academic Press Inc.
3. Keyhani, A. 1997. Heat and Mass Transfer in Layered Seedbed. Unpublished Ph.D. Dissertation. Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Saskatoon, SK.
4. Toth, B. M., and Maulé, C. P. 1993. Temperature Calibration of a Resistive Soil Moisture Sensor. *ASAE Paper No. 93-2557*. St. Joseph, MI: ASAE.
5. Wittrock, V., and Wheaton, E. E. 1991. Climatological Reference Station. Annual Summary. *Saskatchewan Research Council*. Technical Report No. 230.

ساخت و کالیبراسیون بلوکهای گچی کوچک با احتساب دما جهت اندازه گیری رطوبت خاک

ع. کیهانی

چکیده

جهت اندازه گیری میزان آب موجود در لایه های نازک خاک (در حدود ۳۰ میلی متر) بلوک های گچی مرسوم مناسب نمی باشند. برای انجام چنین کاری بلوک های گچی کوچک به روشی ابداعی ساخته شدند. رابطه ای توانی بین میزان رطوبت خاک و قرائت مقاومت الکتریکی بلوک گچی به دست آمد. در کالیبراسیون مشخص شد که قرائت های بلوک های گچی به دما حساس می باشند. با استفاده از روش نرمال سازی، انحراف مقاومت اثر دما بر قرائت های حس کننده ها خنثی گردید. پس از کالیبراسیون، ضرایب قطعیت بالای به دست آمده، استفاده از بلوک های گچی کوچک را برای آزمایش های آینده تضمین نمود.