GRANULAR MATRIX SENSORS FOR IRRIGATION MANAGEMENT*

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Abstract

The goal of this study was to develop an automated and multiplexed measurement system using granular matrix sensors (GMS). The system included 144 sensors connected to three multiplexers and eight temperature probes connected to a single multiplexer. Calibration of the GMS were performed in the laboratory to determine the relationship between resistance and percent mass water content for a Madras loam soil. Sensor curves were plotted to determine the occurrence and location of wetting fronts in the field. An automated and multiplexed GMS system accurately predicted changes in soil water content and the occurrence of wetting fronts. The system described should be useful for field research on many subjects, including investigating plant-soil systems and validation of water-flow models. Without automation, the GMS can be used by irrigators to determine when and how much water to apply.

Introduction

A granular matrix sensor (GMS) has been developed for electronically measuring soil moisture (Larson, 1985). The GMS operates on the same electrical principle as the gypsum block and contains a reservoir of gypsum imbedded in the granular matrix, which minimizes the effect of soil salinity on the resistance measurement. The objective of this study was to determine if an automated, multiplexed GMS system could accurately measure soil water status at several locations, thus providing a profile of soil water content. This was accomplished by calibrating the GMS to soil water content for a specific soil, measuring GMS response to wetting fronts, and by testing the appropriate instruments in the field.

Materials and Methods

Calibration of Granular Matrix Sensors
The calibration was done in a soil material from the A horizon of a Madras loam (fine-loamy, mixed, mesic, Xerollic Durargid). The sensors were planted wet in 8L containers, each containing soil with a different water content percentage, ranging from completely saturated to completely dry. Each container was covered with plastic wrap to reduce loss of moisture due to evaporation. Measurements were then taken everyday for six days until there was no change in the readings.

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Initially, 24 stainless steel GMS Model 200-SS were immersed in 21°C (70°F) water overnight. The sensors were then allowed to dry for one day after soaking. The soak-dry cycle was repeated two more times to improve sensor response. Before installing the sensors in the soil, one more soaking cycle was performed in which the 24 sensors were immersed for three hours. Soil moisture readings were then taken using the WATERMARK Soil Moisture Meter (Irrometer Company, Inc.). The temperature setting was fixed to the appropriate temperature (21°C). The WATERMARK Soil Moisture Meter converts the electrical resistance reading of the sensor to an estimate of centibars of soil tension. The digital readout meter gives a range of -4 to 200 centibars (C), with -4 being completely saturated. This equates to 0 to 27 kΩ electrical resistance (R) according to the following formula,

\[ z = 0.726 + 0.143(C) \]  

[1]

The sensors were removed from the soil, and soil samples (approximately 150 cm³) were taken from each of the three areas in each bucket where the sensors were located. Mass water content was determined gravimetrically. The final readings were used for calibration purposes.

**Instrumentation and Installation**

The initial system consisted of 144 sensors and eight Model 107 Temperature Probes wired to four AM416 Relay Multiplexers. The multiplexers were then controlled using a CR10 Datalogger. All of the above equipment was obtained from Campbell Scientific Inc., Logan, UT. Each of three multiplexers were wired to 48 separate sensors. The fourth multiplexer was wired to eight separate temperature probes. Using coaxial cable, each of the four multiplexers were then wired to a single CR10 datalogger, which took resistance readings (Ohms/10) from the sensors and Celsius readings from the temperature probes. Measurements were taken using the AC half bridge instructions in the CR10 manual with ±2.5 V excitation.

The system was installed in June 1992 in a furrow-irrigated peppermint (*Mentha piperita* L.) field at the Central Oregon Agricultural Research Center at Madras, OR. The sensors were buried in nine different locations in the field. Each location, labeled R-Z, contained one set of 16 sensors. Individual sensors were wired to one of three multiplexers, resulting in 48 sensors per multiplexer. The eight temperature probes were buried at a single location in the field to monitor soil temperature at the relative depths of the sensors. The sensors were buried 152 mm apart, starting in the furrow, and at varying depths, depending upon location in the bed/furrow (Fig. 1). Holes were dug at various depths using an Oakfield soil probe. To insure proper contact, a mud slurry was poured into the hole before burying the sensor. The sensor was then inserted into the narrow hole and more slurry inserted. The hole was then backfilled with soil.

The CR10 Datalogger took resistance and temperature readings every five minutes during irrigation, and once-a-day (at 6:00 a.m.) between irrigations. Once the data had been transferred to the computer, the SPLIT (Campbell Scientific, Logan, UT) software application was used to retrieve the data into ASCII files. These files were later imported.
Results and Discussion

Calibration
The calibration of the sensors yielded a high correlation between resistance and percent mass water content, for a value of \( r^2 = 0.963 \). The best-fitting curve was an exponential (decay) curve represented by the following:

\[
\Theta = a(b)^R, \quad R > .5k\Omega \quad [2]
\]

as shown in Figure 2. When using the WATERMARK soil moisture meter, \( R \) should be substituted with the following:

\[
\Theta = a(b)^{0.143(C)+0.726} \quad [3]
\]

where \( C = \) Centibars measured by the WATERMARK meter. For most practical applications, the \( a \) coefficient (27.1 percent) approximates the maximum water content measurable by the GMS. The equation is also easily manipulated into volumetric water content by multiplying the \( a \) coefficient by the soil bulk density and specific volume of water. The \( a \) coefficient may be given in percent, or as a ratio, without changing the other coefficients of the equation.

Contrary to Spaans and Baker (1992), our data indicates that a common calibration can be used for all sensor blocks. In agreement with Eldredge et al. (1993), the good fit of the model and the strong correlation indicate that the GMS can be used to measure soil water content.

For field readings, a temperature correction factor was determined using the initial temperature setting of the calibrated sensors. Spaans and Baker (1992) showed that the resulting equation for a temperature correction factor was:

\[
R_r = R_m[1+k*(T_m-T_r)] \quad [4]
\]

where \( R_r = \) reference resistance in Ohms, \( R_m = \) measured block resistance in Ohms, \( T_m = \) temperature (°C) at measured resistance (\( R_m \)), and \( T_r = \) reference temperature. The manufacturer of the GMS reported \( k = 0.018 \) at \( T_r = 18.3°C \). Spaans and Baker (1992) reported \( k = 0.024 \) with \( T_r = 25°C \). Thomson and Armstrong’s (1987) findings are numerically similar, although the mathematical expression is somewhat different. Substituting \( R_r \) of equation 4 for \( R \) in equation 2, water content can then be calculated more accurately.

Field Data
The reference resistance, measured resistance, and temperature were plotted against time to examine changes in soil water content. At low resistance (high water content), the temperature correction becomes less critical. The fluctuation in diurnal temperature and water content are out of phase, resulting in a dampening in the fluctuation of the resistance curve due to the temperature. As noted by Jackson (1973), the amplitude of the diurnal
The infiltration and redistribution process are shown in Figure 4 for a period of three days, with a shallow GMS responding quickly to infiltration and drying, and the deeper GMS responding more slowly. A sharp drop in resistance occurs in the sensors near the surface during irrigation, while a gradual decrease in $R$ occurs in the sensors located deeper in the soil. This can be explained if one considers how soil water content changes during the infiltration process. At the beginning of infiltration, the infiltration rate is high, which results in relatively fast soil water content changes at a point behind the wetting front. As time increases, the water becomes transmitted through a wet zone that is continuously increasing in length. This is accompanied by an increase in the resistance to flow and a decrease in the infiltration rate. As the infiltration rate drops in time, the wetting front decreases in velocity and the changes in soil water content immediately behind the wetting front more time.

**Conclusion**

WATERMARK sensors allow for multiplexed, automated, *in situ* measurements for determining changes in soil water content and the onset of wetting fronts when such occur abruptly in the field. The system described here proved reliable, effective, and cost efficient, exhibiting only minor problems. The GMS have advantages of low unit cost and ease of installation and automation. Once installed, data acquisition can be remote from the measurement site. The main disadvantage of this type of system is poor calibration of the sensors near saturation (low end of the scale), which may not be critical for field studies or for practical applications such as irrigation scheduling. Occasionally, malfunctions occur due to poor electrical conductivity or bad connections to the multiplexer. Currently, this type of system is being used in furrow irrigation research at Central Oregon Agricultural Research Center, and Malheur Experiment Station.

**References**


Figure 1. Diagram of individual WATERMARK sensor set, Madras, OR 1992.

Figure 2. GMS calibration for water content of Madras loam. Open squares represent data not included in the regression, Madras, OR 1992.
Figure 3. Temperature and Resistance, Madras, OR 1992.

Figure 4. Infiltration and Redistribution, Madras, OR 1992.