FIELD MEASUREMENTS OF SOIL-WATER CONTENT AND SOIL-WATER PRESSURE

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Accurate and frequent measurements of soil-water content and soil-water pressure are necessary for studies concerning the movement of water in field soils--such as during infiltration, and redistribution. Knowledge of the dynamic water content-pressure potential relationship within the soil profile is useful in determining the importance of hysteresis under natural conditions.

Continuous monitoring of water content in the field is now possible using recently developed gamma-ray transmission equipment which allows water content measurements in 1-cm-thick soil layers with an error of 0.009 gram per gram [Reginato and Jackson, 1971]. Soil-water pressure can be measured in these layers with small ceramic tensiometers connected to sensitive pressure transducers with an error of 1 to 2 cm water [Watson, 1965].

This paper describes the equipment and procedures used to determine water content and pressure potential continuously in the top 10 cm of a field soil over a 2-week period following an irrigation. Data for 4 days during this 2-week period for one soil depth demonstrate the type of information obtainable by this method.

EQUIPMENT

Nuclear Equipment

The nuclear equipment used was described previously [Reginato and Stout, 1970]. Briefly, the equipment consisted of a high-voltage power supply, amplifier, scaler and timer, spectrum stabilizer, and single-channel pulse analyzer which was set to monitor transmitted gamma photons in the energy range of 0.644 to 0.680 Mev. This equipment was housed in an air-conditioned building about 50 m from the measurement site.

A 5-mCi source of ^{137}Cs was positioned 20 cm from the scintillation detector. The crystal, 1 cm thick and 3.8 cm in diameter, was mounted on a photomultiplier tube with built-on voltage divider. The source and detector assemblies were connected to a mounting plate, which was raised and lowered by a gear rack and gear motor. A tripod, which held the motor 2.5 m above the soil surface, was positioned over vertical access tubes within which the source and detector moved when the soil profile was scanned.

A controller device was designed and constructed to automatically and repeatedly position the source detector assembly at various depths within the soil profile. This device positioned the source and detector assembly at a depth, remained at this depth until the count and the location or depth of probes were recorded, moved the assembly to the next location, measured, and recorded again. After measuring and recording at the final depth, the assembly was automatically repositioned at the first location, and the measurement sequence repeated. The soil profile was continually scanned in 1-cm increments starting at the 0- to 1-cm soil depth, such that each layer was measured every 15 minutes.

Tensiometer Assembly

Tensiometers were constructed from double-bore porous ceramic tubes with a bubbling pressure of approximately 1.4 bars. A piece of tygon tubing connecting the two holes at one end of the ceramic tube was epoxied in place. Two 30-cm lengths of 18-gauge stainless steel tubing were inserted into the holes in the other end of the ceramic tube and epoxied in place. The ceramic tensiometers, 4- to 5-cm o.d. and 10-cm long, were inserted horizontally from a hole dug adjacent to the measurement site with just the stainless steel tubes extending from the soil. A bidirectional pressure transducer was attached with a small piece of tygon tubing to one of the stainless steel tubes coming from the tensiometer. Air was flushed from the system by opening the vent port of the pressure transducer and forcing de-aerated water into the open stainless steel tube through the ceramic tensiometer and back out through the transducer. The free end of the stainless steel tubing was then closed off with a small piece of plastic tubing and hose clamp. The tensiometers were installed 1.5, 2.5, 3.5, 5.5, 7.5, and 9.5 cm from the soil surface. The pressure transducers were placed in a watertight container in the hole adjacent to the measurement site, and voltages from the transducers were recorded on a digital data-logging system every 30 minutes. This tensiometer installation was located about 3 m from the gamma-ray transmission site.

PROCEDURES

Gamma-Ray Transmission

To calibrate the gamma site, it was assumed that the soil profile was horizontally homogeneous. Gravimetric samples were taken vertically in 1-cm increments to obtain a profile of gravimetric water content versus depth.

With this information and concurrent measurements of the count rate through the 1-cm increments, the bulk density profile for the experimental site was calculated using [Reginato and Jackson, 1971]:

$$\rho_s = \frac{\ell n\ (I_o/I)}{x\mu_w\ (0.93 + \theta_w)} \quad . \tag{1}$$

Subsequent scanning of the soil profile with the gamma apparatus allowed soil-water content data to be obtained as a function of depth and time. Gravimetric water contents were calculated using:

$$\theta_w = \frac{\ell n\ (I_o/I)}{x\mu_w\rho_s} - 0.93 \tag{2}$$

and volumetric water contents were obtained by multiplying equation (1) by equation (2). It was assumed that the bulk density at each measurement depth remained constant.

The volumetric water content was calculated for every 15 minutes for each depth. Two techniques were used to smooth the data. First was a numerical-averaging procedure, using the data from the two measuring periods prior to and following the specific measuring period of interest. This technique helped to reduce the scatter due to errors in random emission of the gamma-ray source. Second was to plot these values of water content as a function of time, and to draw a smooth curve through points to obtain the average water content change with time for each depth of interest.

Tensiometers

The voltage output from each of the six tensiometers was recorded every 30 minutes. These data were subsequently converted to millibars pressure from a calibration obtained in the laboratory. The pressure potential was then plotted as a function of time. No smoothing was required.

RESULTS AND DISCUSSION

Volumetric water content and pressure potential for the 1- to 2-cm soil depth are shown in Fig. 1. Data collection began 20 hours after the site was flooded with 10 cm of water, and data for the following 4 days are presented. Climatic conditions during this period were characterized by clear skies, low winds, and air temperatures ranging from -1 to 20 C.

Several points are immediately obvious. First is the rapid loss of water from early morning to early afternoon each day. Second is the gain in water during the mid afternoon and evening. Third is the diminishing amplitude of this diurnal change with time after irrigation. Fourth is the relatively uniform reduction in the average water content during these four days.

The highest water content was measured each day just before sunrise. Water content (about 0.01 $cm^3\ cm^{-3}\ hr^{-1}$) declined rapidly until 1300-1500 hours, which coincides with the time of maximum air temperature. Water then started to accumulate in the 1- to 2-cm soil layer until the next sunrise at an average rate of 0.003 $cm^3\ cm^{-3}\ hr^{-1}$. The net result of the depletion and accumulation of water was an average loss in volumetric water content of 0.02 $cm^3\ cm^{-3}\ day^{-1}$ during this 4-day period.

Pressure potential is plotted against time in Fig. 1 for the same 4-day period. The pressure potential, obtained from a tensiometer located at a depth

of 1.5 cm, decreases most rapidly as the water content declines, but not exactly in phase as one might expect. Also, the increase in pressure during the night levels off for a long period as opposed to the sharp peak of the water content curve. This time lag difference between water content and pressure may be due to hysteresis, difference between the soil conditions at the tensiometer and gamma rig sites, or, more likely, temperature effects on the pressure transducer.

Temperature effects in a tensiometer-pressure transducer system have been discussed by Watson and Jackson [1967]. Their work was confined to a laboratory in which the period of the temperature fluctuation was on the order of 4 minutes. The temperature effect decreased with increasing conductance of the ceramic and with increasing period of the temperature fluctuation. The laboratory data indicated that temperature effects would be minimal under field conditions. However, the experiments reported here, and subsequent experiments indicate that temperature does affect the measurement of soil-water pressure in field situations. Further research is needed to quantify the effect and to develop means of circumventing it.

From Fig. 1 and data taken after this 4-day period, a moisture characteristic curve was constructed and is shown in Fig. 2. No hysteresis is apparent. The error in volumetric water content determinations is approximately $\pm$ 0.015 $cm^3\ cm^{-3}$.

SUMMARY AND CONCLUSIONS

Soil-water content and pressure in the top 10 cm of a field soil profile were measured continuously for a 2-week period following an irrigation. Water contents were determined in 1-cm soil increments with a gamma-ray transmission technique using a 15-minute scanning interval. Soil-water pressure was

measured every 30 minutes at six depths in the top 10 cm of soil with a tensiometer-pressure transducer system.

There were larger diurnal changes in water content than in pressure potential. This may have been due to temperature effects on the pressure-measuring system. A moisture characteristic curve was constructed from these data.

Continuous measurements of soil-water content and soil-water pressure are necessary to describe in more detail the patterns of soil drying following irrigation. Knowing explicitly the drying patterns in the soil profile may lead to a better evaluation of the effectiveness of applied and naturally occurring mulches to conserve water.

REFERENCES

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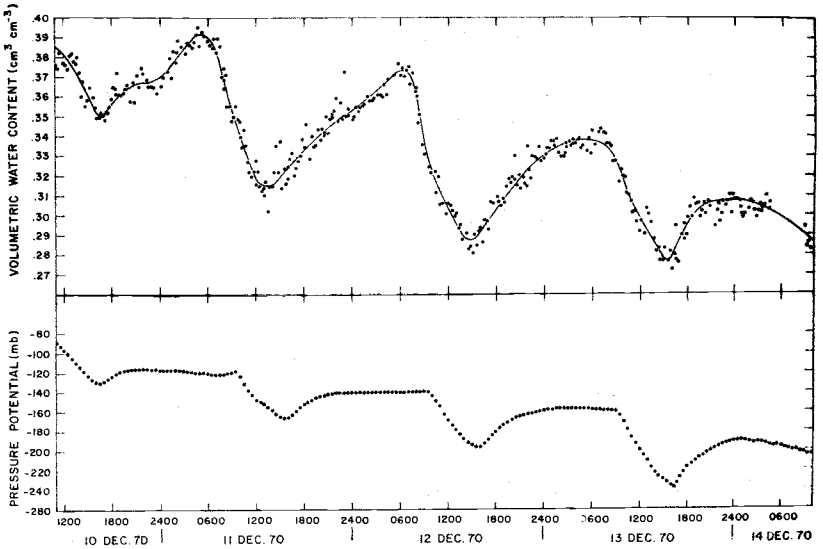

Figure 1. Volumetric water content and pressure potential in the 1- to 2-cm soil depth starting 20 hours after irrigation with 10 cm of water.

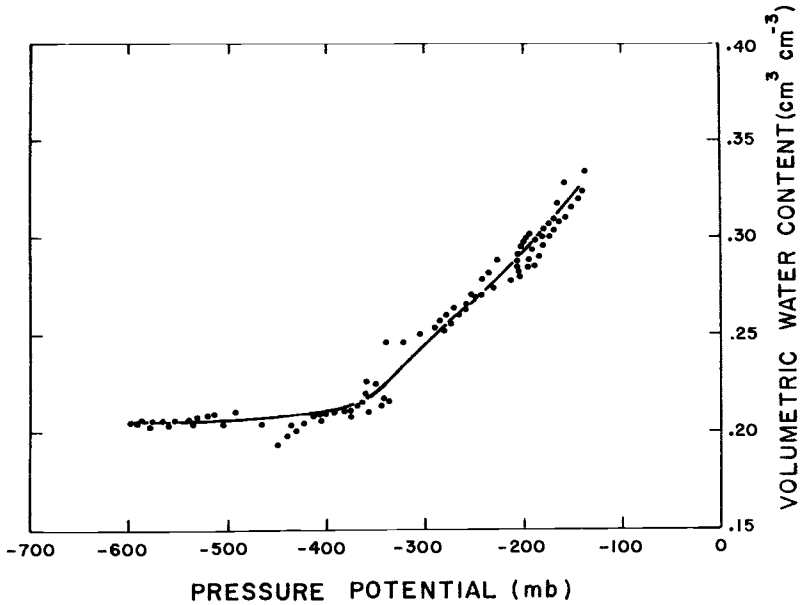

Figure 2. Moisture characteristic curve obtained from volumetric water content-pressure potential data taken from 1200 on 10 December 1970 to 1200 on 24 December 1970, MST.