PROGRESS REPORT

IAEA Research Contract Number: 11186/FAO

Title: Accuracy and Precision of Neutron Scattering, TDR, and Capacitance Methods of Soil Water Measurement

Institute: USDA-ARS Conservation and Production Research Laboratory, Bushland, Texas

Chief Investigator: Steven R. Evett, Ph.D.

Period: April 1, 2000 through March 31, 2001

The project proposed to compare three profiling water content measurement systems with the neutron probe. Despite the proposed project start date of April 1, funding for this project was delayed until July 21, 2000 due to contractual difficulties. Funding granted ($5,000.00) was one quarter of that requested and sufficient only for one of the systems. Some equipment was acquired in August, 2000, too late for work in the weighing lysimeters during the summer. Other funding was obtained from three Groundwater Conservation Districts in the Texas Panhandle. This funding was also delayed due to contractual difficulties. Work on the main project thus began in fall 2000 when all instruments were at hand. However, work with a prototype instrument began in May 2000 as described below.

Sheathed TDR Probe

In May 2000, contact was made with Environmental Sensors, Inc. (ESI) and agreement was made to include a prototype sheathed TDR probe in the study. Dr. Jason Sun visited for three days in early April and worked with us on access tube installation and use of the sheathed probe. However, during this visit we found that the equipment provided did not allow for installation of the access tubes with close contact to undisturbed soil. Equipment consisted of a spiral auger that created an oversized hole in our tough clay soil.

Work on the prototype probe and access tube installation methods proceeded during summer 2000. We suggested design modifications for the probe, including changing the head to a vertical orientation to allow work within close crop canopies and adding a handle to it (Fig. 1), and designing a shoe to allow depth referencing from the soil surface rather than the top of the access tubes (Fig. 1). A second prototype with these design changes was delivered; and the work described herein was done with it. We also cooperated with ESI on tube installation methods, and fabricated two bucket augers for augering inside of a steel guide tube to create a hole for installation of the plastic center access tube (the center of three tubes, the other two being on either side and being of galvanized steel - Fig. 1). Due to the small diameter of these bucket augers (2 cm),

plugging of the augers in our clayey soil was common and it took as long as one day to ream a hole to the full depth of 1.5 m. Unfortunately, withdrawal of the steel guide tube caused disturbance of the soil around the tube; and this method was discarded without obtaining any field measurements. Future plans include testing another tube installation method using a cutting edge on the bottom of the plastic tube and a steel guide tube fitting closely to the inside dimension of the plastic tube. Also, ESI is considering a prototype with a larger diameter that would ease installation in problem soils such as ours.

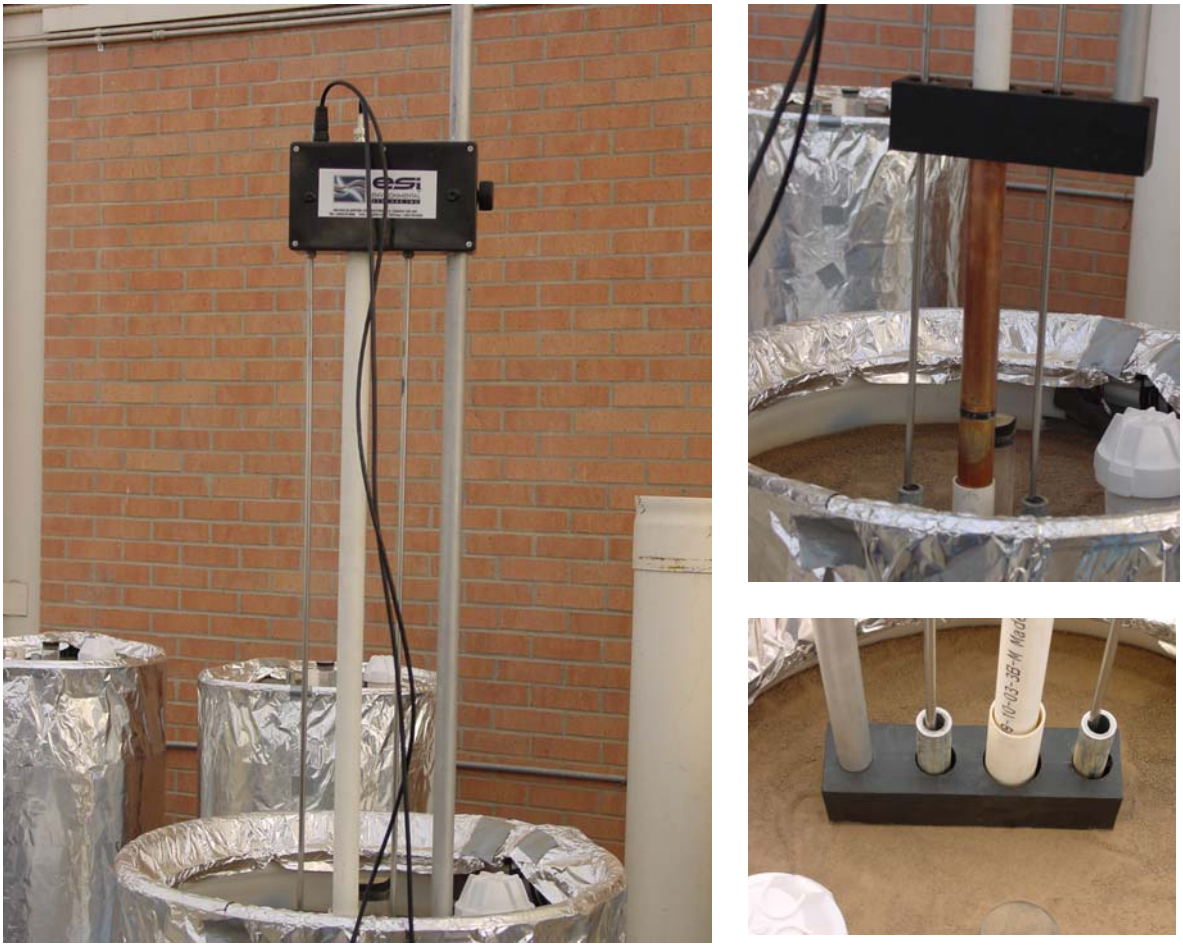

Fig. 1. Prototype sheathed TDR probe inserted to second depth range (20-40 cm) (left). Black knob on right side of head is for depth adjustment. Prototype sheathed TDR probe being inserted into three access tubes (top right). The surface reference shoe is visible at the top of the picture. The waveguide consists of the copper tubing visible entering the middle, white plastic tube; and the ground rods entering the two steel tubes on either side. When inserted for the first reading, the shoe rests on the soil surface with the three access tubes protruding above it (right bottom). The aluminum tube on the left side is fixed permanently to the shoe and slides up and down within the probe head.

Probe Comparison in Soil Columns

Three soils were acquired in fall 2000, air dried, crushed and sieved to 2-mm diameter (Fig. 2). The soils were 1) a silty clay loam derived from the A horizon of a Pullman soil (30% clay, 53% silt), 2) a clay derived from the Bt horizon of a Pullman soil (48% clay, 39% silt), and 3) a clay loam (35% clay, 40% silt) derived from the Bk horizon of a Pullman soil containing 50% $CaCO_3$. The Pullman soil is a fine, mixed, superactive, thermic Torrertic Paleustoll with mixed clay mineralogy including a large proportion of montmorillonite. The difference in clay content from 30 to 48% between soils 1 and 2 should cause any texture dependence of measurement methods to show up. The 50% $CaCO_3$ content of soil 3 should cause any effects of soil chemical composition on measurements to show up.

Fig. 2. Three soils after crushing and sieving (left). Soil 1 (clay) is in the back. Soil 2 (silty clay loam) is in the foreground. Soil 3 (50% $CaCO_3$) appears to be nearly white. Nine deck scales and data logger for soil column mass measurement (right).

Soil was packed uniformly into three replicate columns for each soil. Soil in each column was 75-cm deep and 55-cm in diameter, and rested on a 5-cm deep drainage bed of fine pure silica sand in which was embedded a ceramic filter tube specified at 100 kPa air entry potential. Soil was packed in 5-cm layers around access tubes, which were held in place with a jig so that tube positions would be identical in each column (Fig. 3). Horizontal, trifilar TDR probes (20-cm length) were installed at 2, 5, 15, 25, 35, 45, 55, and 65-cm depths in each column to measure soil water content, and thermocouples were installed at the same depths to measure soil temperature. Samples for water content were obtained every two layers. Column sides were covered with reflective aluminum foil to minimize diurnal heating and cooling on the sides. Column soil surfaces were left exposed to solar radiation and air temperature variations in the green house that housed the experiment.

Column mass was measured every 6 s using a data logger (Campbell Scientific, Inc., model CR7, Logan, Utah) connected to the paralleled output of the four load cells in each deck scale (WeighTronix, Inc.), using a six-wire bridge configuration to minimize temperature induced errors. Mean values were output every 30 min. Calibration with test masses traceable to NIST resulted in a precision of approx. 50 g (Fig. 4).

Fig. 3. Access tubes fixed in place prior to soil packing (left), and soil column with access tubes and cables for TDR and thermocouples after packing.

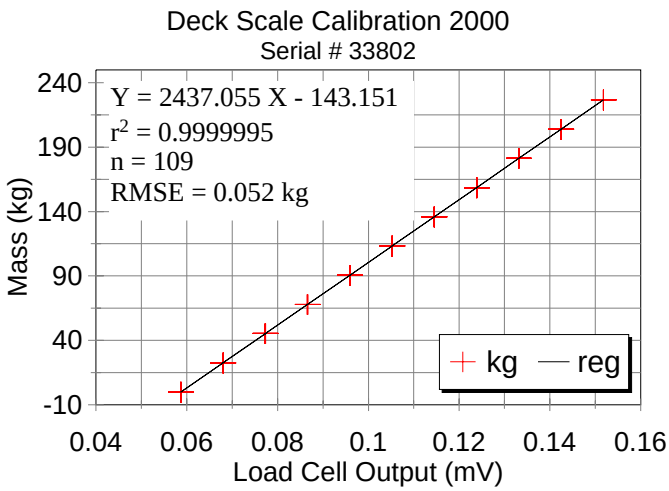

Fig. 4. Example of calibration results for deck scales used to measure soil column mass.

Measurements of soil water content with the 63 20-cm trifilar TDR probes were made every 30 min using the TACQ program (Evett, 2000ab) running a system composed of an embedded computer (IBM PC/AT compatible), cable tester (Tektronix, model 1502C), and five coaxial multiplexers (Evett, 1998).

Two capacitance type soil water measurement systems were used (Sentek Environmental Technologies, Kent Town, South Australia, models EnviroScan and Diviner 2000). The Enviroscan system features a string of sensors placed every 10 cm on a plastic backbone through which a communications cable runs to the sensor string head (Fig. 5). Sensors were placed to measure 10-cm high intervals centered at 5, 15, 25, 35, 45, 55, and 65 cm. One string of sensors was placed in one column of each soil and logged continuously every 30 min. The Diviner 2000 consists of a single sensor, similar to that used in the EnviroScan, fitted to a square rod that allows the sensor to be lowered to 1.6-m depth in an access tube. The same size PVC plastic access tube is used for both Sentek systems

(5.1 cm inside diameter, 5.6 cm outside diameter). We made readings every other day in two columns of each soil with the Diviner 2000 at the same depths as for the EnviroScan.

Two profiling TDR systems were used. One was the prototype trifilar probe design from ESI called a sheathed probe, described above. The other was a cylindrical probe with two opposing waveguides oriented vertically along the cylindrical body (Fig. 6) (IMKO Micromodultechnik, GmbH, Ettlingen, Germany, model TRIME-T3 Tube Access Probe). The measurement length of the tube probe is 17.5 cm. We made measurements at 17.5-cm depth intervals with the top-most measurement centered at 8.75 cm below the soil surface. Daily measurements were made. The sheathed probe has a 20-cm measurement length. We made daily measurements at 20-cm depth intervals with the top-most measurement centered at 10 cm below the soil surface. With both systems, a measurement was also made with the probe resting against the bottom of the access tube.

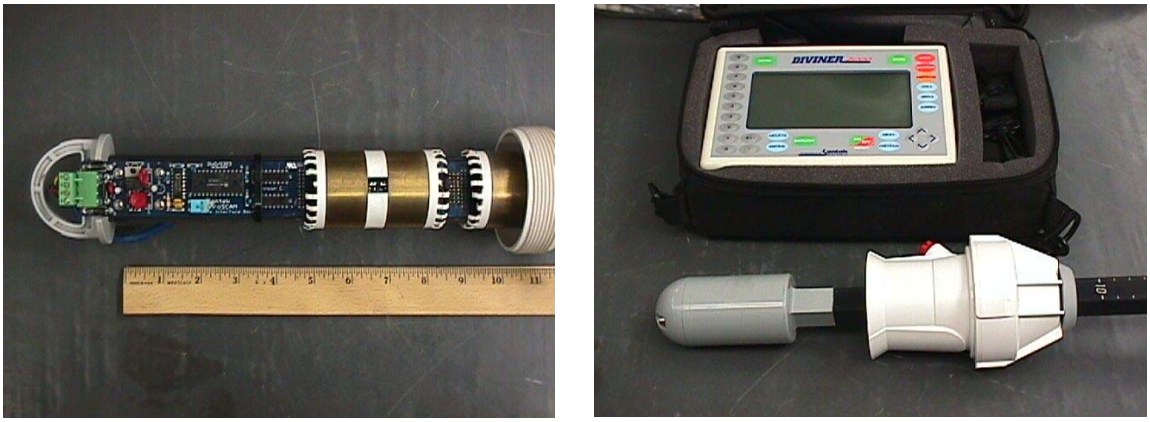

Fig. 5. Sentek EnviroScan sensor string partially removed from access tube (left). The communications circuit is visible just to the right of the green connector on the left. One complete sensor is shown with two brass rings separated by white plastic and with white plastic fingers on either end. The Sentek Diviner 2000 probe is in a gray plastic housing (right). A square rod passes through the white head, which rests on top of the access tube during use. Sensors in the rod signal the portable data logger (top right) as to the depth of the probe as the probe is moved up and down in the access tube.

Results to Date

Temperatures in the soil columns varied diurnally by up to 16ºC due to solar radiation in the green house (Fig. 7). Temperature variations decreased with depth, indicating that the reflective shielding was effective in preventing heat loading on the sides of the columns. Corresponding soil column mass measurements indicated that temperature effects on water content derived from mass measurements were <0.01 m^3 m^{-3} (Fig. 7).

Data from the EnviroScan system showed a temperature effect that was also on the order of 0.01 m^3 m^{-3} (Fig. 8). Data from the Diviner 2000 was in the range from 0.05 to 0.08 m^3 m^{-3}, comparable to that from the EnviroScan, and about 0.03 m^3 m^{-3} larger than actual.

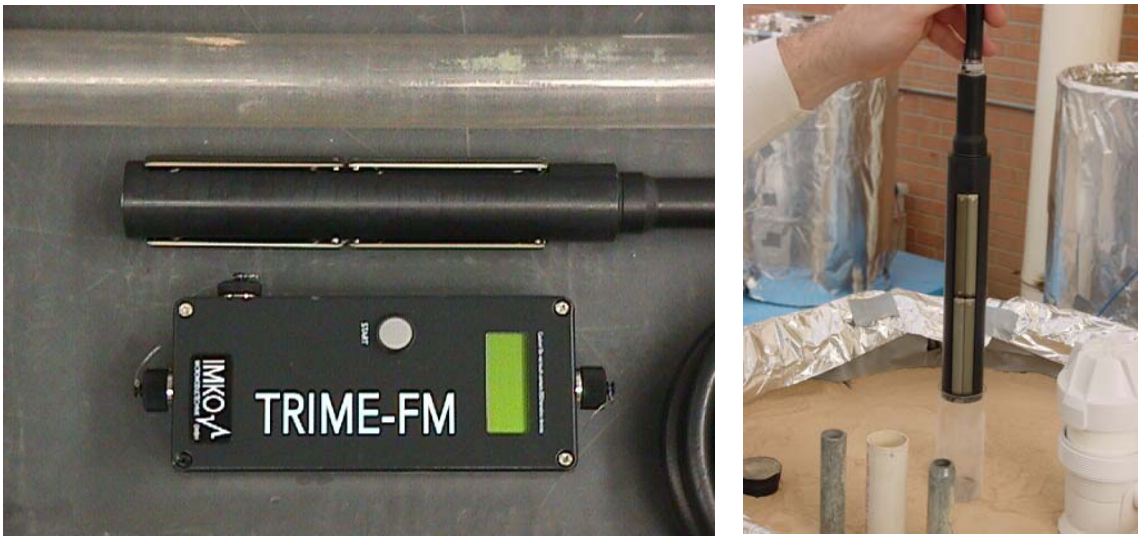

Fig. 6. The Trime tube probe and readout with an access tube (left). The tube probe being inserted into an access tube prior to a measurement (right).

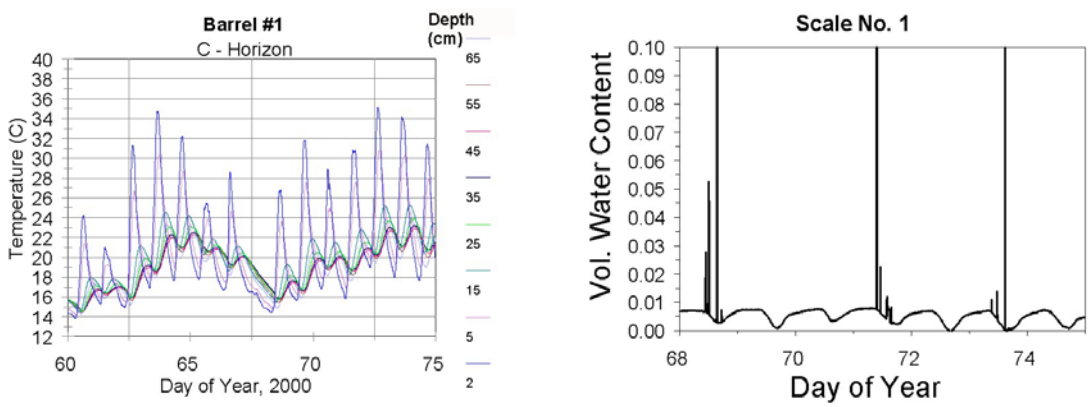

Fig. 7. Example of temperature variations in soil columns by depth (left). Temperature effect on water content derived from scale mass measurements was <0.01 m^3 m^{-3} (right). Spikes in water content are due to persons and instruments being placed on scales.

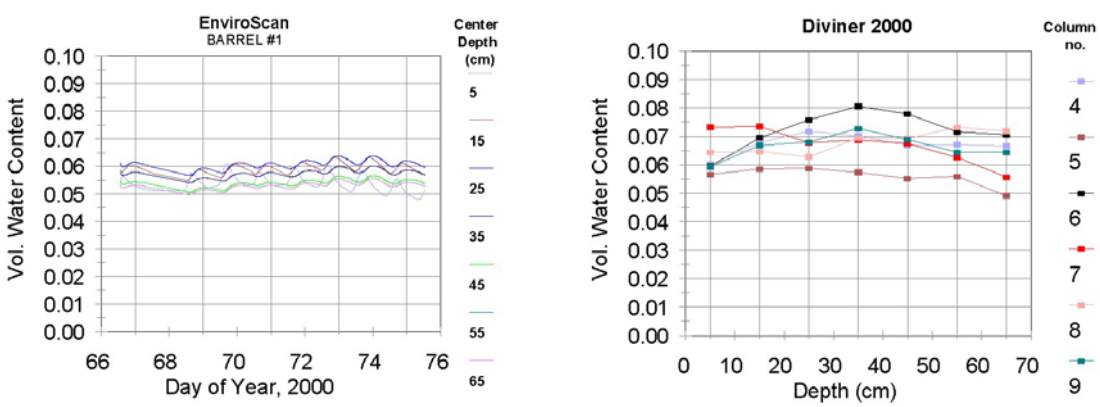

Fig. 8. Example data from EnviroScan system (left) and Diviner 2000 (right, day 68).

Water content values from the Trime tube probe ranged from 0.07 to 0.11 m^3 m^{-3}, about 0.06 m^3 m^{-3} larger than actual (Fig. 9). Water contents from the prototype sheathed probe were obviously incorrect due to lack of calibration (Fig. 9). The range of readings was as large as that from the Trime system. The increase of water content values with depth may be due to incorrect cable lengths in the prototype.

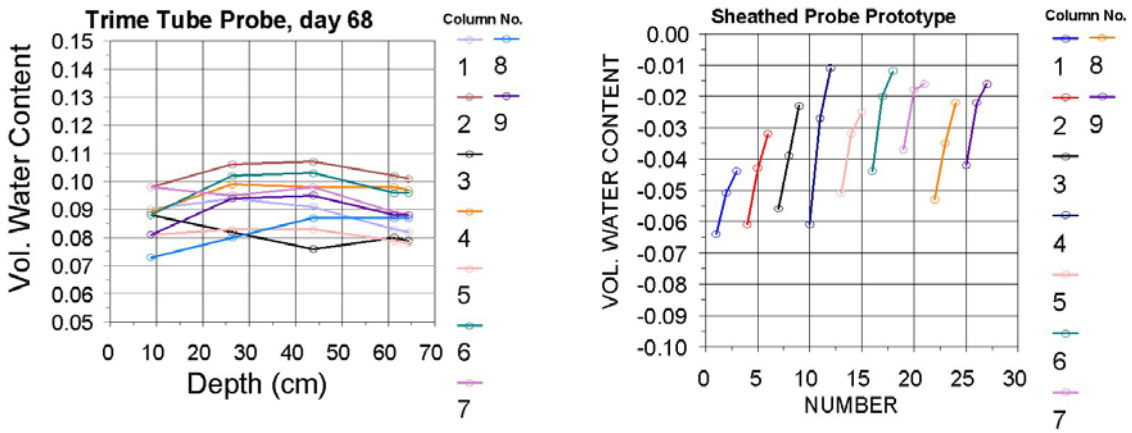

Fig 9. Water contents from the Trime tube probe (left). Water contents from the prototype sheathed (right). Depth increases from left to right in the graph at right.

Neutron probe water contents were only approximately correct due to the limited volume of the soil columns and the nearness of access tubes (Fig 10). Nevertheless, results for the $CaCO_3$ rich horizon were surprisingly good. For the other soils there was a marked negative error at depths below the 10-cm reading. The conventional TDR performed better than other methods, giving readings quite close to those determined on the air dry soil during packing (Fig. 10). The 0.01 m^3 m^{-3} lower value for the probe at 2-cm depth is partially due to continued soil drying at that depth (visible in Fig. 10), and may be partially due to closeness to the soil surface. Temperature effects resulted in water content errors much smaller than 0.01 m^3 m^{-3}, except for the probe at 2-cm depth, which sometimes showed temperature induced fluctuations nearing 0.005 m^3 m^{-3} (Fig. 10).

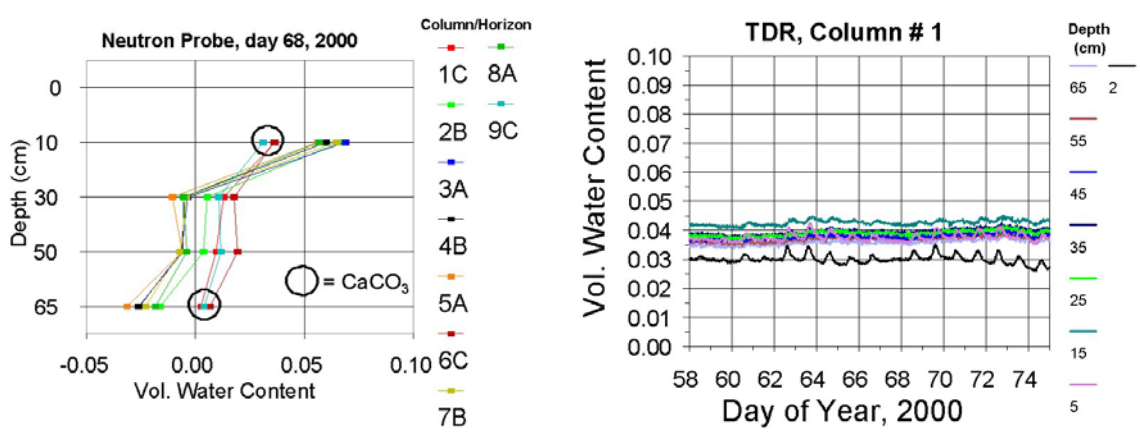

Fig 10. Example neutron probe results (left) and conventional TDR results (right).

Conclusions

It is still too early to draw conclusions from this study, although it is clear that without additional calibration the conventional TDR system has been the most accurate so far. Experiments taking place at this time include measurement of temperature effects on the manual (not data logged) instruments, obtained by repeated measurements over two or more diurnal cycles (30 min intervals). Before the columns are wetted, experiments on the sensitivity of the instruments to the soil-air interface will be conducted. Columns will then be wetted slowly from the bottom while measurements continue. Once the columns are saturated with water, experiments on the sensitivity of the instruments to the soil-air interface will be repeated, followed by experiments determining the temperature effect at saturation. Columns will then be drained, first by gravity, followed by suction at 100 kPa, while measurements continue. A late summer wheat or rye crop will be planted to further dry the columns as measurements continue. After harvest, the columns will be resaturated and experiments on soil water salinity experiments will be performed.

Other Activities

A paper on this research project has been submitted for presentation at the Annual International Meeting of ASA, CSSA, SSSA, Oct. 21-25, Charlotte, North Carolina, USA.

During the summer and fall of 2000, the chief investigator collaborated with another contract holder, Mr. Cliff Hignett, in writing the chapter on the neutron scattering method of soil water measurement for the upcoming revised book, *Methods of Soil Analysis.*

References

Evett, S.R. 1998. Coaxial multiplexer for time domain reflectometry measurement of soil water content and bulk electrical conductivity. Trans. ASAE 41(2):361-369. (Available at http://www.cprl.ars.usda.gov/programs/)

Evett, S.R. 2000a. The TACQ Program for Automatic Time Domain Reflectometry Measurements: I. Design and Operating Characteristics. Trans. ASAE vol. 43(6):1939-1946. (Available at http://www.cprl.ars.usda.gov/programs/)

Evett, S.R. 2000b. The TACQ Program for Automatic Time Domain Reflectometry Measurements: II. Waveform Interpretation Methods. Trans. ASAE vol. 43(6):1947-1956. (Available at http://www.cprl.ars.usda.gov/programs/)