

AN IMPROVED TECHNIQUE FOR SOIL SOLUTION SAMPLING IN THE VADOSE ZONE UTILIZING REAL-TIME DATA

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Abstract. The vadose zone is an area of ongoing concern because of its role in the fate and transport of chemicals resulting from waste disposal and agricultural practices. The degree of contamination and movement of solutes in soil solution are often difficult to assess due to temporal variability in precipitation or irrigation events and spatial variability in soil physical properties. For this reason, modeling groundwater and contaminant migration in unsaturated soil is crucial in determining the extent of the contamination. Unfortunately, manual methods used to sample soil pore water and validate model results are often inefficient due to the variable nature of the vadose system. Manual techniques are traditionally performed at arbitrary intervals without specific knowledge of the conditions in the soil at the time of sampling. This hit or miss approach can lead to missed samples, poor sample recovery, and samples that are not representative of the event of interest. In an effort to target specific soil conditions at the point of sampling that are conducive to successful sample acquisition, an automated lysimeter sampling and fraction collector system was developed. We demonstrate an innovative technique coupling real-time data with soil solution sampling methods which will improve the efficiency and accuracy of contaminant sampling in the field. The infrastructure of this system can also be implemented in a laboratory setting which adds to its practicality in characterizing soil hydraulic properties and model development.

INTRODUCTION

Typically, pore water samples for chemical analysis are collected from the vadose zone using suction lysimeters installed at specific depths. During sampling, a vacuum is applied to the lysimeter to draw moisture from the surrounding soil materials. Success in sampling, however, depends on the degree of saturation in the materials adjacent to the lysimeter, a factor beyond the control of the person sampling, and the level of vacuum that can be achieved, making it difficult to collect pore water samples on a preset, routine schedule, as is the normal practice for groundwater monitoring. The Automated Vadose Moni-

toring System (AVMS) was designed to address such limitations.

MATERIALS AND METHODS

System description

The AVMS consists of the following core components: (1) data I/O control unit; (2) soil moisture sensors; (3) soil matric potential tensiometers; (4) suction lysimeters; (5) lysimeter vacuum pumping system; (6) sample fraction collector/storage unit; and (7) associated sample tubing and control wiring (Figure 1). The number of associated soil moisture sensors and tensiometers may vary depending on the specific application. Any reliable soil moisture indicator or soil matric tensiometer can be incorporated within the current system as long as it is compatible with the datalogger/instrument control apparatus.

Additional features that may be included in the AVMS consist of battery power sources recharged through solar panels mounted near the system to supply sufficient power in remote locations. The AVMS may be used as an irrigation control system using soil moisture trends to ensure that moisture levels in the rhizosphere are maintained within a desired range. The system can support flow meters and irrigation control valves that link with the datalogger and soil moisture sensors for irrigation control.

The in-ground sensors and samplers associated with the prototype AVMS at a field test site consist of soil moisture probes, soil matric potential sensors, and suction lysimeters. These instruments measure volumetric soil moisture, soil matric potential, and soil water at user defined time intervals. Three of the four clusters (1, 3, and 4) were instrumented with soil moisture probes measuring soil water content at 1, 2, 4, and 6 feet and suction lysimeters at 2, 4, and 6 feet. The fourth cluster (2) was more heavily instrumented with soil matric potential sensors at 1, 2, 4, and 6 feet in addition to the same sensors in clusters 1, 3, and 4 (Figure 2). Corresponding suction lysimeters were installed at 2, 4, and 6 feet in close proximity with the soil moisture probes.

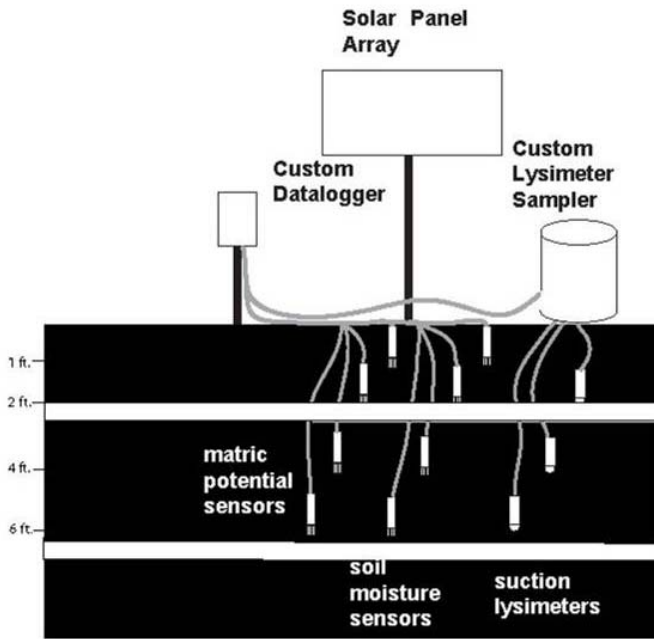


Figure 1. Sensor and lysimeter placement with depth.

The soil moisture probes operate on principles that are related to traditional time-domain reflectometry (TDR) measurements using the intrinsic differences in dielectric constant that exist between the soil and water within the soil when a current is applied through the measuring rods of a probe. The AVMS soil moisture probes use high frequency sinusoidal signal to measure the impedance of that signal and subsequent dielectric permittivity in the associated medium (Miller and Gaskin, 1999). Soil moisture is calculated according to the linear relationship between the dielectric constant and volumetric water content that has been established in the literature (Whalley, 1993; White et al, 1994; Topp et al, 1980). The soil moisture probe is accurate to $\pm 0.05 \text{ m}^3/\text{m}^3$ using generalized soil calibrations based on general organic and mineral soil characteristics that bracket the range of most soil types. Calibration to a specific soil type is possible, and increases sensor accuracy to $.01 \text{ m}^3/\text{m}^3$. The soil moisture probes were installed by taking a soil core to the desired installation depth. The probes were carefully inserted into the bore hole and the probes were pushed securely into the soil at the bottom of the hole. A slurry mixture was made with the core soil and poured back into the hole to insure that no air pockets were inadvertently left around the probe. The bore hole was then backfilled and capped with bentonite clay at the surface.

Soil matric potential sensors are modified soil moisture probes used to measure soil matric tension. The soil moisture probe's measuring rods are embedded in a porous material (the equilibrium body) with a known, stable relationship between water content and matric potential. When the soil matric potential sensor is installed at the

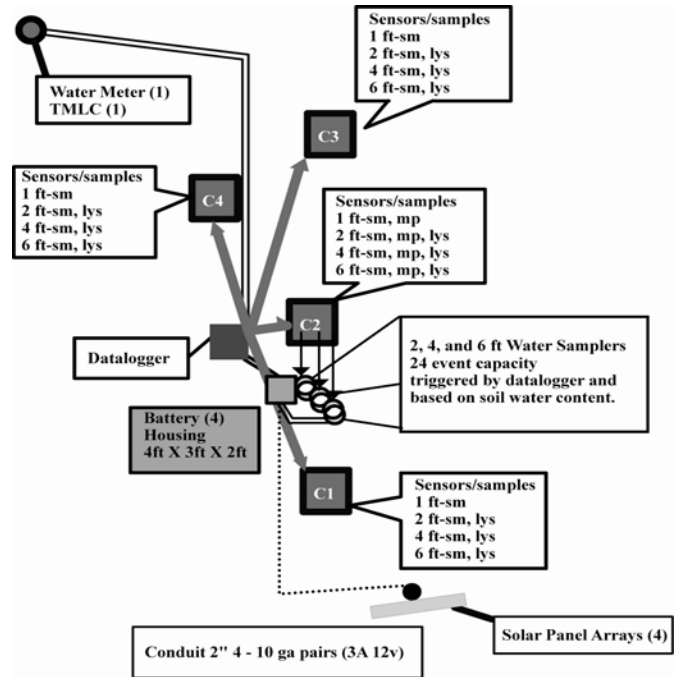


Figure 2. Plot layout and sensor distribution of the AVMS in the field.

desired depth, the matric potential within the porous material equilibrates with that of the surrounding soil. The soil moisture sensor portion of the matric potential probe measures water content of the material which is then converted to matric potential using a calibrated relationship specific to each probe (Delta-T Devices, 1999). Installation of the matric potential probes was similar to that of the soil moisture sensors, but the probes were soaked in deionized water before installation. Added care was taken when pouring the slurry mixture to insure contact between the porous ceramic material in the instrument and the surrounding soil.

The suction lysimeters, equipped with 2 bar porous ceramic cups, were installed at depths of 2, 4, and 6 feet. Efforts were made during the installation process to isolate the porous cups at the soil depth of interest. The suction lysimeters are directly controlled with three custom programmable portable auto-samplers. The vacuum is applied and sample removed using the pumping features of the samplers. The multi-sequence aspect of the custom sampler is programmable and allows the collection of soil water fractions over time. Currently, there are three lysimeter samplers in operation at the site which allow sampling at 2, 4, and 6 foot depths within a cluster or at a particular depth between any three clusters. The pumps on the custom lysimeter samplers are peristaltic pumps that provide measured vacuum tensions of up to 50 kPa. The instrument controller uses an external trigger supplied by the custom datalogger to initiate lysimeter sampling when field conditions are adequate. Suction head and line

transport velocity range from 3 feet of head and 3.0 ft./second to 25 feet of head and 2.2 ft./second.

System control

The AVMS sensors and custom lysimeter samplers are ultimately controlled and monitored by a custom measurement and control system consisting of a 16-channel datalogger with an additional 32-channel input multiplexor added to increase the measurement system's channel capacity. The datalogger is a 12 volt-powered programmable measurement and control system designed to measure 6 differential or up to 12 single-ended analog data channels. The programmable module provides sensor measurement, communication, data reduction, data/program storage and control functions. The custom operating system is designed to perform multitasking operations, allowing for simultaneous communication and measurement functions. The datalogger runs on a simple event-driven operating system. A program is called at user specified time intervals at which time the logger reads field sensors, and, if necessary, sends control signals to the custom lysimeter samplers to begin lysimeter sampling. Lysimeter sampling is based on flags that are turned on or off based on soil moisture conditions monitored with soil moisture sensors in the field. Currently, the AVMS reads field sensors every fifteen seconds and stores an average of those reading every fifteen minutes. The data and program are stored in either the datalogger's non-volatile flash memory or battery-backed RAM. The data is downloaded to a Windows compatible laptop PC over a serial link.

An additional feature included in the AVMS is a flow meter that registers the volume of water being applied to a specific irrigation plot. The flow meter is a low flow paddle-wheel flow meter that is installed in the 3" irrigation line which supplies the plot. The flow velocity range of the flow meter is 0.1 to 6.0 m/s. The meter is capable of operating within the irrigation line at up to 180 psi. Power to the flow meter is supplied via the datalogger, which also monitors the flow meter output.

RESULTS

System Testing

Initial testing of the AVMS has demonstrated the benefits of near-continuous data collection as opposed to point data collection. Figure 3 shows soil moisture data collected with the AVMS compared to weekly data collected with more traditional TRIME-TDR and gravimetric methods in the lab. The data represent the soil moisture reading at 15 minute intervals at depths of 1, 2, 4, and 6 feet averaged across clusters 1 – 4 for Feb. 3 to Feb. 24,

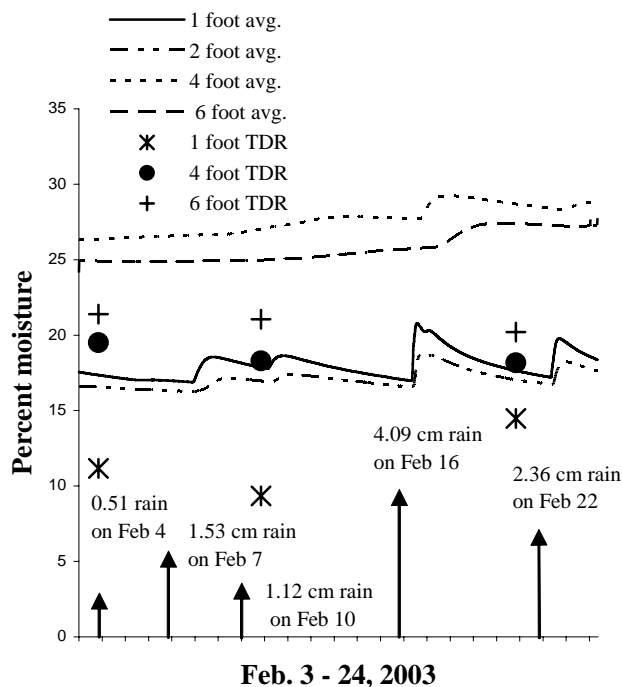


Figure 3. Automated vs. manual soil moisture data with respect to rainfall events.

2003. The paucity of data and lack of any trend (either daily or weekly) in the point observations are apparent when precipitation events are included in the analysis, with precipitation clearly evident in the AVMS data. Also, there is more detail observed at each depth throughout the plot. As expected, the near surface sensors responded quicker and more drastically to the precipitation events. These data are representative of the beneficial nature of the AVMS over traditional soil parameter measurement techniques.

CONCLUSION

In summary, the system uses water content and matric tension sensors installed at various depths within the profile to actuate pumps that apply a vacuum on the lysimeter only when the soil moisture level is such that a pore water sample can likely be collected, the sample is then transferred to a fraction collector where it is stored for pickup at one's convenience. Telemetry systems can be used to remotely monitor and control the AVMS, and power at remote locations can be supplied by batteries that are charged by solar panels. The increase in data detail from continuous monitoring of soil moisture and matric potential, both in quality and quantity, is crucial in improving the efficiency of sampling soil water with the lysimeter samplers. Real-time monitoring of soil tensions allow the

system to initialize lysimeter sampling at the appropriate time, while soil moisture measurements provide a measure of how much water is available for sampling during a sampling event. Since soil tension, soil moisture, and solute concentration are all important in estimating the amount of water and solute in the vadose zone, increasing the quality and quantity of these data and improving the efficiency of soil water sampling leads to better mass balance estimates of water and solute movement through the soil.

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