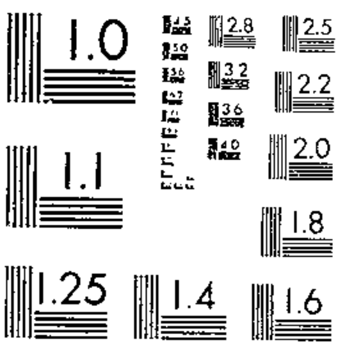
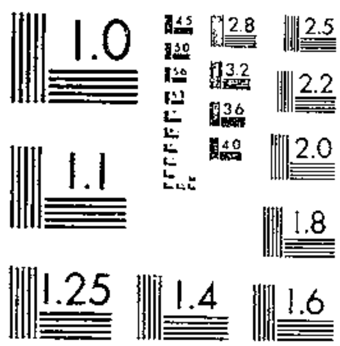
TB 1562 (1977) USDA TECHNICAL BULLETINS UPDATA
DESIGN, INSTALLATION, AND USE OF POROUS CERAMIC SAMPLERS FOR MONITORING
LINDEN, D.R. 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

Design, Installation, and Use Of Porous Ceramic Samplers For Monitoring Soil-Water Quality

Technical Bulletin No. 1562

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
In cooperation with
Minnesota Agricultural Experiment Station

Abstract

D. R. Linden. Design, installation, and use of porous ceramic samplers for monitoring soil-water quality. Agricultural Research Service, U.S. Department of Agriculture, Technical Bulletin 1562, 16 pp.

Surface, ground, and soil-water samples are used to evaluate the quality of a water system. Surface water can be sampled easily, ground water can be taken from wells, but soil water, which is held in the soil pores by strong forces, cannot be easily removed for analysis. Porous ceramics, however, enable removing a water sample from unsaturated soils and subsequent analysis just as surface water and ground water can be sampled and analyzed. Sampling soil water instead of, or in addition to, surface and ground water will often result in a more adequate description of potential pollution hazards.

This report describes how to use porous ceramic samplers, how to construct a soil-water sampling system, how and where to install samplers, and how to obtain samples. It is intended as a guide for users of porous ceramic samplers who have little or no background knowledge of soil, hydrology, or geology.

Keywords: suction cup lysimeters, soil water sampling, porous ceramic.

Contents

Washington, D.C. June 1977

Design, Installation, and Use Of Porous Ceramic Samplers For Monitoring Soil-Water Quality

Dennis R. Linden[1]

Porous Ceramic Samplers and Soil Water

Soil water is held in the pore space of soils by forces on the surfaces of soil particles and within the water. These holding forces become stronger as soils become drier. The strength of this holding force and the amount of water held in the soil for two typical soil types are shown in figure 1. Clay soil contains more water than the sand at any holding force. These holding forces are commonly described by equivalent suctions or tensions and are expressed in such common pressure terms as atmospheres (atm), bars, or centimeters (cm) of water or mercury. Soil water held at suctions greater than 0.1 to 0.3 atm is relatively immobile; however, water at less suction is relatively mobile and moves freely in the soil. When free drainage occurs in soils, they will drain to 0.1 to 0.3 atm suction within 24 to 48 hours. The water content associated with this 24- to 48-hour drainage is referred to as the field capacity.

Water held in soils will be displaced by new water entering the soil. Soil water will thus become ground water as it is displaced downward into this larger reservoir. Figure 2 is a diagram showing ground, soil, and surface water.

Soil water can be sampled when the suction that holds the water in the soil is overcome with a porous ceramic device. Suction is overcome by applying a counter force to the air-water interface by means of a vacuum inside a porous ceramic sampler. Figure 3 shows soil and soil water in contact with the porous ceramic and the air chamber on the opposite side of the ceramic wall.

The porous ceramic is similar to a very fine soil, and when placed in contact with moist soil, its pores will be completely filled

---

[1]Soil scientist, Agricultural Research Service, U.S. Department of Agriculture, St. Paul, Minn. 55108

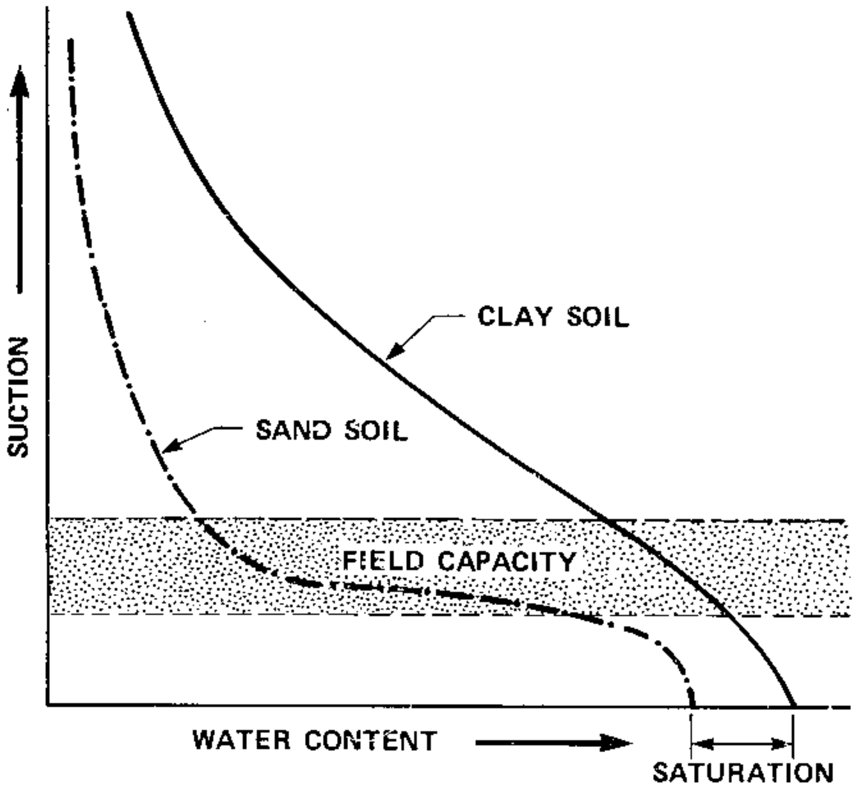


Figure 1.—Soil-water suction versus water content for two soil types.

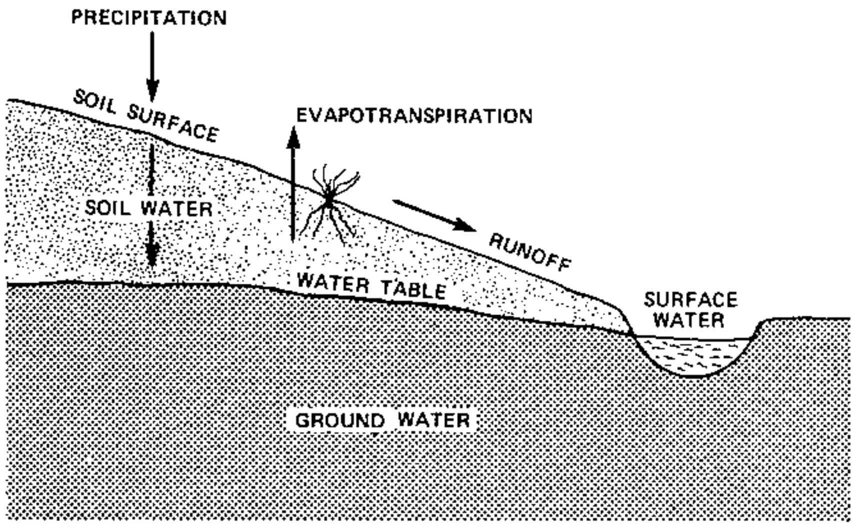


Figure 2.—Schematic of the relation between ground, soil, and surface water.

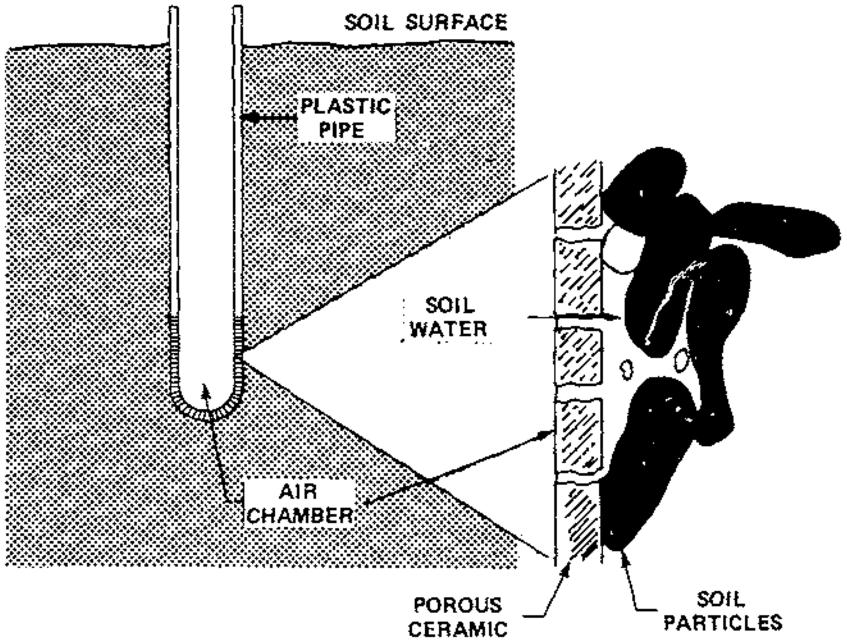


Figure 3.—Cutaway view of a cup-type porous ceramic sampler.

with water. When the air is evacuated from the air chamber, a suction is applied to the water in the ceramic walls. Water will move into the chamber if this applied vacuum is stronger than the suction in the soil. When the sampler has collected enough water for analysis, the chamber can be opened and the sample removed.

Porous ceramic samplers cannot sample water held in soils above 1 atm suction because they are limited to the air vacuum that can be applied to the inside of the ceramic wall. Ceramic samplers can, however, be used to sample water at any suction below 1 atm including water at zero suction that could be removed from the soil through an open well.

Design of a Sampling System

Several alternative designs of a sampling system are possible. The alternatives involve the shape of the ceramic, suction application, and sample removal. These three features will be discussed separately to allow selection of the system that best meets the objectives of sampling.

Shape of the Ceramic and the Flow Pattern

Two basic configurations are possible. The simplest configuration is a ceramic cup. A cutaway view of a ceramic cup, which is a symmetrical cylinder with one end closed and one end open, is shown in figure 4. The closed end is normally a continuation of the porous ceramic material but also could be a plug. The open end is usually attached to a piece of plastic pipe that alternatively could be glued, threaded, or friction fitted to any nonporous tubing. These cups are available commercially in several sizes and come either factory attached to plastic pipe or as individual items.

Soil-water flow into the cup is radial from all directions around the cup. The amount of flow coming from any direction will depend on how strongly the water is held in the soil at that position. For example, if the cup shown in figure 4 is just above a water table (water held at zero suction), most of the water moving into the cup would come directly beneath the cup because water to the sides

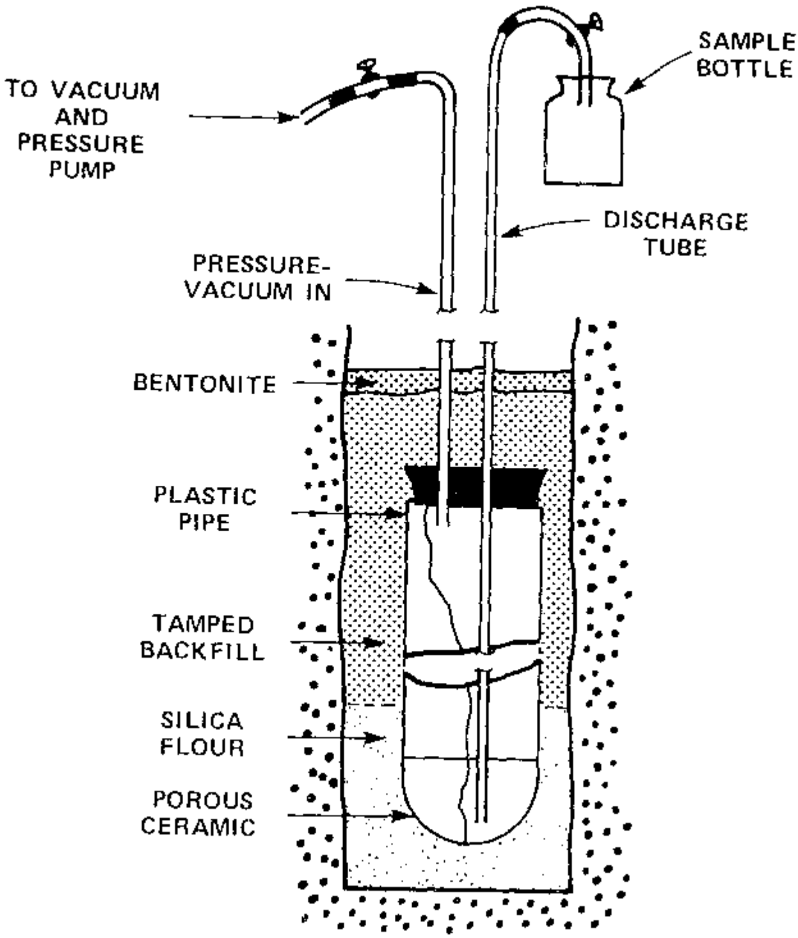


Figure 4.—Installing ceramic sampler in the soil (7).

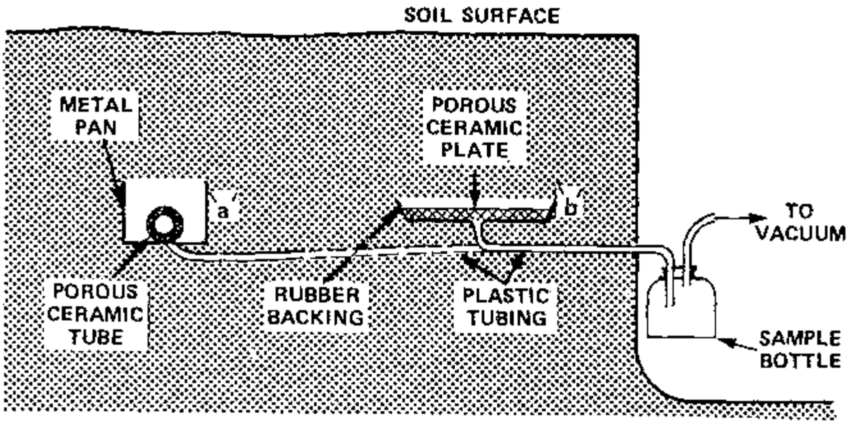


Figure 5.—Vertical flow (volumetric) type porous ceramic samplers.

and above the cup would be at higher suctions. In a uniform soil well above the water table, flow into the cup would be nearly uniform from all directions.

This configuration has the advantage of simplicity and the disadvantage of ill-defined, sample flow patterns. The objective of the sampling will determine the relative importance of these advantages and disadvantages. The advantages of a well-defined (only vertical) flow pattern will be discussed in the following section.

The second configuration is a slight modification of the first (fig. 4). The water moving through the ceramic wall comes only from directly above the ceramic. Devices like those shown in figure 5, placed well above a water table, will sample only from a vertical downward direction. The first device "a" uses a ceramic cylinder as in figure 4. It restricts, however, flow from the bottom and sides with a stainless steel pan. The second device "b" uses a flat ceramic plate with a small air chamber on the underside and a rubber backing. These devices are also commercially available but are somewhat more expensive than ceramic cups.

Vacuum must be continuous to achieve volumetric sampling and must be controlled to prevent convergence or divergence of water flow in the vicinity of the sampler. Volumetric sampling would be achieved by measuring the soil water suction just above the sampler and at a second point in the undisturbed soil to the side of the sampler and by adjusting the vacuum to keep these two points at the same suction. These conditions can be approximated with deep pans (fig. 5 "a") or by constant low vacuums (0.1 to 0.3 atm).

Volumetric sampling allows converting concentrations into the total mass by taking the product of volume and concentration. This total mass can be converted to a unit area basis by dividing the mass by the area of the sampler. This mass-per-unit area can be expressed in the common units of pounds or tons per acre (kilogram per hectare) by using the proper conversion factors. The mass-per-unit area, determined by this volumetric sampling, is the estimate of the downward movement during the sampling period and can be expressed on a unit time basis by dividing by the sampling period.

The primary advantage is that flow into the sampler is restricted to the downward direction. The disadvantages are the increased cost and complexity. Haise and Duke (*3*)[2] detail construction, installation, and use of this type of sampler.

Applying Suction

Access to the air chamber of the porous ceramic sampler is necessary to evacuate the air and cause water to enter the chamber. Any airtight and closable access to this chamber is satisfactory. Vacuum can be applied continuously or intermittently with a hand- or motor-driven pump. Intermittent applications of vacuum followed by closing the chamber are satisfactory for sample collection. One or more applications of suction may be necessary to obtain a sample.

Continuous vacuum systems would maintain at a high level the forces causing waterflow into the cup and would thus allow sample collection in a shorter time. Continuous vacuum, however, requires a motor-driven vacuum pump, which greatly increases the costs. The vacuum should be the lowest possible values that will allow sample collection. Vacuum levels between 0.3 to 0.8 atm are generally sufficient for sample collection. Lower vacuum levels (0.3 atm) are desirable because only the most mobile water would be sampled. Higher vacuum levels would be necessary in drier soils.

After applying vacuum and collecting the sample, the air chamber can be opened and the sample removed. A simple way to do this is to place a rubber stopper with access for suction application in the end of the plastic pipe. This stopper can be removed and a small-diameter tubing inserted into the chamber. The sample can be pulled up into a container through this tubing by applying vacuum to the container.

A second possibility is shown in figure 4 as a double-tube method—a slight modification of the first method. The sample removal tube is left in place, and the sample is removed by apply-

---

[2]Italic numbers in parentheses refer to References, p. 11.

ing a small air pressure through the vacuum access port pushing the sample up through the discharge tube into a container. This method has the advantage of forcing some of the collected sample to flow back through the ceramic wall and into the soil. The backflushing will aid in moving very fine soil particles, which tend to plug the ceramic pores, away from the wall. Ceramic plugging is a major problem with these samplers, which is discussed in more detail on page 8.

Several other modifications of sample removal are possible, including a check valve arrangement that allows sampling at much greater depths or at remote, inaccessible sites. Wood (9) describes additional details on this apparatus.

Some care must be taken in the choice of materials used for sample collection. Ideally, tubing should be inert plastic, nylon, or stainless steel to prevent metal contamination, sorption on the tubing walls, and reactions that will modify the concentrations of various constituents. Choice of tubing will be governed by the objective of the sampling and the type of analysis to be made.

Installing Samplers

This section will cover some details about handling samplers to ensure the collection of reliable samples. The discussion will include washing, placing, contacting with soil, ceramic plugging, and proper backfilling to prevent water channeling directly into the ceramic cup.

Porous ceramics should be washed with dilute acid before use to remove contaminants left in the cup during manufacturing. Several milligrams per liter of sodium and calcium and some phosphorous and nitrogen are in the cups before washing. Vacuum can be applied to an assembled device and 250 to 500 ml of 0.1N HCl solution followed by deionized water pulled through the ceramic wall to the inside chamber and discarded. This washing is particularly important to remove such cations as calcium and magnesium from the ceramic.

The assembled samplers are now ready for installation at the sampling site. They should be soaked in water before installation so that porous ceramic walls are completely filled with water. The overriding principle of good installation is to obtain *good contact* between the soil and the ceramic wall. Good direct contact is necessary to have a continuous pathway for soil water movement to the wall, through it and into the inside chamber. In some cases good contact can be achieved by carefully backfilling a hole about 2 inches in diameter larger than the ceramic cup and tamping around the porous ceramic with the soil removed from the hole at that depth.

Two possible modifications of this installation will often ensure better contact and more reliable sampling. First, a slurry of the soil material from the augered hole could be poured around the ceramic cup and settled with a tamping rod. This method will eliminate large voids that would restrict the contact area of the cup with soil. This technique will most often ensure good operation of the sampler.

A second slurry technique is to use a very fine silica sand (silica flour) slurry around the ceramic cup to ensure good contact. A volume of slurry just large enough to completely surround the cup should be poured into the open auger hole and the sampler pressed firmly into the slurry. The hole can then be tamp backfilled. This technique is particularly useful in coarse sands and gravels. The second technique is recommended to give the best assurance of good, reliable samples in most soils for some time.

After installing the ceramic sampler, the augered hole should be slowly refilled with continuous tamping to eliminate any large voids that could channel water directly to the ceramic cup from the soil surface. In some cases include a plug of bentonite sealer in the hole to ensure against this direct channeling. Mounding soil around the surface exposed sampling tube will ensure that ponding and channel flow along the pipe will be minimized.

The pores in ceramic material will plug in time as soil particles, organic matter, and microbial growth migrate to the wall of the ceramic. The silica flour slurry and backflow air pressure sample removal are two techniques to ensure longer sampling life of porous ceramics. Operation for 3 years or more should be possible with these techniques while sampling may be limited to one season when no precautions are taken. Samplers may need to be removed periodically and backflushed to remove some of this plugging material. Backflushing in place may help some, but it will also introduce considerable water into the soil.

Placing Samplers

The exact number, location, and depth of samplers will be determined by the objective of the sampling and the size of the system. Some general guidelines, however, will aid in obtaining data that are reliable and representative.

First, sample at least two depths in a soil profile to obtain a time rate of movement factor and the influence of changes within the soil profile. In systems in which plant uptake is a factor, at least one sampler should be below the root zone or 5 to 6 feet deep depending on the crop. Many constituents (such as nitrate nitrogen) in water below the root zone change little and will eventually reach a ground- or soil-water derived surface water supply.

Thus, sampling at a 5-foot depth will indicate the water quality that would reach much greater depths and ground water at later times.

Second, sample the variations in soil within the system. Typically, soils may change from sands to clays in soil depths over short overland distances and thus have much different water-conducting properties. For example, a small area of sandy soils within a system might indicate considerable ground-water contamination whereas the major portion of the system with finer soils removes contamination well. Soil layering such as pans and gravel lenses will often restrict vertical water movement and cause considerable horizontal flow on sloping soils. Sampling should be just above these layers and include downslope sites to detect this horizontal movement.

Third, sample background concentrations whenever possible. Install samplers before the disposal or other system becomes operational.

Fourth, sample any differences in treatment within the system so that individual components of the system can be properly evaluated.

Sample in sufficient numbers, so that probabilities of real effects may be established. Statistical analysis of data is necessary to establish this probability level and to draw valid conclusions. Soils are naturally nonhomogeneous and considerable sample variation should be expected; however, replication of samples will allow any nonhomogeneity in soil to be analyzed correctly and to assess a real effect or pollution potential. Two is the minimum number of replications and may, under some conditions, be all that are necessary. Three or more replications, under more variable conditions, would be desirable. Ten or more replications may be necessary to define details of the soil-water profile.

Scheduling Sampling

Frequency of intermittent sample collection will depend upon the objective of the sampling. Sample as often as necessary to obtain data that represent the system and meet the objective. If sampling is used only to indicate that a potential pollutant has reached the sampling depth, then regular-interval sampling such as once or twice per month may be satisfactory. If sampling is used to indicate the total contribution to pollution, then sample often enough to describe adequately the concentrations with time. This may mean sampling at short-time intervals during periods of rapidly changing concentrations such as spring thaw and following heavy rains. Intermittent vacuum application should be just long enough to collect a sufficient sample for analysis.

Continuous sampling is necessary to get quantitative flow volumes. As a general rule, schedules for sampling should include: Sample as early in the spring as possible, sample at short-time intervals during spring thaw and rapidly warming soils, sample soon after each major precipitation event, and sample at least monthly if no other schedule is followed.

Physical, Chemical, and Biological Changes in Water Quality

Porous ceramics are similar to soil so that they will absorb and exchange various constituents as a soil would. Fortunately, the thickness of the ceramic wall is usually small, and these effects do not pose a major limitation to their use.

Porous ceramics can also act as screens or filters for large particles. Fortunately, these particles are also filtered in the soil and are not of major concern as potential pollution.

Biological transformations can occur within the sampler; therefore, samples should be removed soon after collection. With this precaution, biological or chemical activity of the collected sample is not a serious limitation. Hansen and Harris (*4*) detail some of these effects.

Use of Porous Ceramic Samplers

Because porous ceramic samplers can sample water in unsaturated soils, sampling can often be done much closer to a source of potential pollution than ground water or surface water sampling. The system can be evaluated and the management altered before large-scale pollution occurs. Because sampling is close to a specific potential pollution source, the problem of dilution with water from other sources is reduced. Thus, a truer picture of how the system is performing can be obtained. Good, clear samples can often be obtained with porous ceramic samplers when sampling could be done through an open well. Because of sediment, dilution, or contamination that might occur from well samples, however, the results may be more difficult to interpret than those obtained from ceramic samplers.

References

(1) Cole, D. W. 1958. Alundum tension lysimeter. Soil Science 85: 293-296.

(2) Duke, H. R., E. G. Kruse, and G. L. Hutchinson. 1970. An automatic vacuum lysimeter for monitoring percolation rates. U.S. Department Agriculture ARS-41-165.

(3) Haise, H. R., and H. R. Duke. 1973. Vacuum extractors for measurement of downward percolate of water and chemical constituents in soils. Soil Science Society of America Proceedings 37: 963-964.

(4) Hansen, E. A., and A. R. Harris. 1975. Validity of soil-water samples collected with porous ceramic cups. Soil Science Society of America Proceedings 39: 528-536.

(5) Harris, A. R., and E. A. Hansen. 1975. A new ceramic cup soil-water sampler. Soil Science Society of America Proceedings 39: 157-158.

(6) Krone, R. B., H. F. Ludwig, and J. F. Thomas. 1951. Porous tube device for sampling soil solutions during water spreading operations. Soil Science 73: 211-219.

(7) Parizek, R. R., and B. E. Lane. 1970. Soil-water sampling using pan and deep pressure vacuum lysimeters. Journal of Hydrology 11: 1-21.

(8) Wagner, G. H. 1962. Use of porous ceramic cups to sample soil water within the profile. Soil Science 94: 379-386.

(9) Wood, W. W. 1973. A technique using porous cups for water sampling at any depth in the unsaturated zone. Water Resources Research 9: 486-488.

END