Gamma Rays Determine Soil Water Content of Soil-Plant Systems

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Water availability throughout the growing season affects crop production. Researchers use neutron meters to obtain soil water information necessary to monitor changes in soil water content in the field and to evaluate the performance of crops (1).

Researchers conduct many experiments with soil-plant systems during the non-field growing season in the laboratory, growth chamber or greenhouse. However, monitoring changes in soil water content and its distribution in the soil profile on a day-to-day or even week-to-week basis is not a common practice when conducting research with actively growing plants in the laboratory or greenhouse. Yet, knowledge of the soil water status is invaluable in interpreting many research results. Plants subjected to soil moisture stress during even a short time have been shown to produce less vegetation and/or grain than well-watered plants.

Soil systems used in greenhouse and laboratory investigations usually are too small to permit use of the neutron method referred to above to monitor soil water. Destructive sampling of the experimental soil system and subsequent gravimetric determination of water content is an accurate way to evaluate soil moisture. But this approach is of limited use when working with small soil-plant systems employed in most greenhouse and laboratory experiments.

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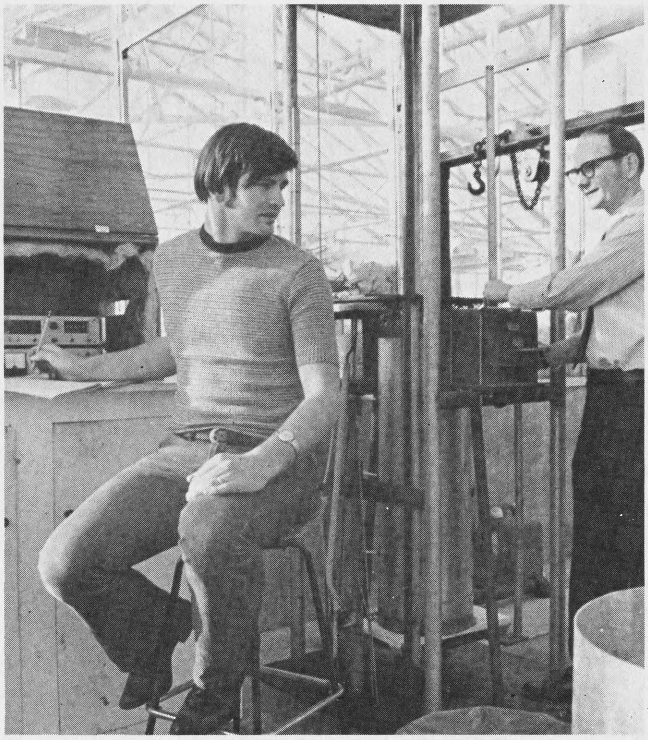

Figure 1. A view of the complete gamma-radiation attenuation unit. The "elevator" framework supports a movable carrier for elevating soil cores. Krueger records data at left, while Dr. Cassel shows the radiation unit.

One or two gravimetric samplings is often enough to alter the soil system so that the intended experimental conditions no longer exist. Tensiometers have been used in laboratory, greenhouse and field situations to monitor changes in soil moisture tension; soil moisture tension is directly related to soil water content. The use of tensiometers is limited, however, to measuring soil moisture tensions between 0 and 800 millibars (14.7 psi = 1000 mb). At a soil moisture tension of 800 millibars, approximately 40 to 50 per cent of the available water remains in sandy soils, 50 to 75 per cent remains in loamy soils, and 75 to 90 per cent remains in clayey soils (clay and silty clay).

During the past decade, a new technique has been developed to determine soil water content. This method utilizes a source of gamma radiation to measure the water content in soil systems (2), and does so to an accuracy of $\mp$ 0.3 per cent by volume. The water content of the soil can be determined without physically disturbing the soil-plant system under consideration. Moreover, the water content is determined at a specific soil depth to $\mp$ ¼ inch, compared with the neutron probe which provides an average water content over a spherical volume of soil ranging from 6 to 12 inches in diameter.

Up to the present, however, use of the gamma radiation method generally has been restricted to measuring changes in water content in soil systems too small to be useful for meaningful research involving plant growth. To conduct laboratory and greenhouse research that is more representative of field conditions, larger soil systems—preferably undisturbed soil—must be used. But large soil systems are heavy and difficult to handle. For example, a 12 x 12 x 40-inch soil column packed with air-dry sand to a bulk density of 1.7 grams per cubic centimeter weighs about 340 pounds.

Recently, a gamma radiation attenuation unit for monitoring soil water content in large cores of undisturbed soil was designed, built and put to use in soils research at North Dakota State University. This paper discusses that particular unit.

THE GAMMA-RADIATION ATTENUATION UNIT

Figure 1 shows the entire gamma-radiation attenuation unit. It consists essentially of two separate systems: (1) a radiation system which consists of a radioactive source — Cesium 137 (137 Cs) — and the electronic components to detect the intensity of the desired gamma-radiation energy levels,

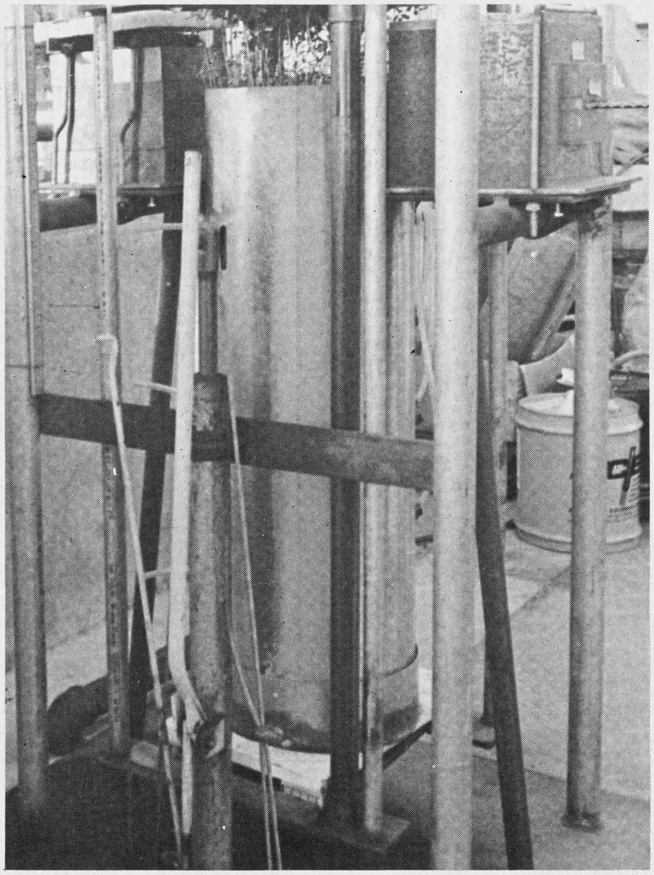

Figure 2. The proportion of gamma radiation emitted from the Cs 137 source housed in the center of the lead block passing through the soil core is detected by the scintillation detector. The radiation intensity is displayed on a scaler-timer. The hydraulic jack is used to elevate the movable carrier holding the soil core.

and (2) a transportation system used to elevate and lower the core of undisturbed soil relative to the radioactive source and detector.

Radiation System

In practice, gamma-radiation from a 250 millicurie 137 Cs source is directed through the soil at any desired location along the column. The radioactive source is housed in the center of an 8-inch lead cube (Figure 2). Part of this radiation is absorbed by any material through which it passes, such as soil solids, soil water, and the container holding the soil. By independently determining the densities and thickness or widths of the soil system and container, the amount of gamma radiation absorbed by the soil water can be calculated. As water content of a soil increases, the amount of radiation passing through it decreases. Conversely, as the water content of a soil system decreases, the amount of radiation passing through it increases.

The amount of radiation passing through the soil system is detected by a scintillation detector. Signals of the desired energy level are totaled for one minute and displayed by a scaler-timer.

Transportation System

The transportation system is used to maneuver the soil system into desired position(s) to determine

Figure 3. The hoist is used to lower the soil core onto a dolly, which is then pushed onto the movable carrier. The movable carrier is then elevated to the desired height(s) and the water content determined.

the water content. It is rigid and requires only one person to operate. The transportation system is essentially a miniature elevator consisting of a steel framework which supports a movable carrier. Construction details are available elsewhere (3).

Because soil cores used in studies to date have weighed as much as 300 pounds, a system was devised to move them to and from the gamma-radiation unit. Each individual soil core rests on a separate 12 x 24-inch movable dolly, equipped with swivel wheels. The hoist (Figure 3) is used to transfer the soil core to a second dolly, which is then pushed into the desired position on the movable carrier of the elevator. One person can readily maneuver the heavy cores in this manner. The movable carrier is raised and lowered by means of a hydraulic jack arrangement (Figure 2). After the water content has been determined at the desired soil depths, the above procedure is reversed and the process repeated for another core.

APPLICATIONS

Below are listed several areas of research in which the gamma-radiation system is currently being used at North Dakota State University. The system may be used in conjunction with any problem where it is desirable to monitor changes in soil water content at specific depths.

1. Infiltration

Infiltration is the process of water entering the soil surface. The infiltration rate is a soil physical property which influences runoff, erosion and the rate at which irrigation water may be applied. Information relative to infiltration rates and soil water holding capacities can be studied, using undisturbed soil cores.

2. Soil Moisture Extraction Patterns of Various Crops

The usefulness of the unit in ascertaining changes in soil water in a soil profile over time is

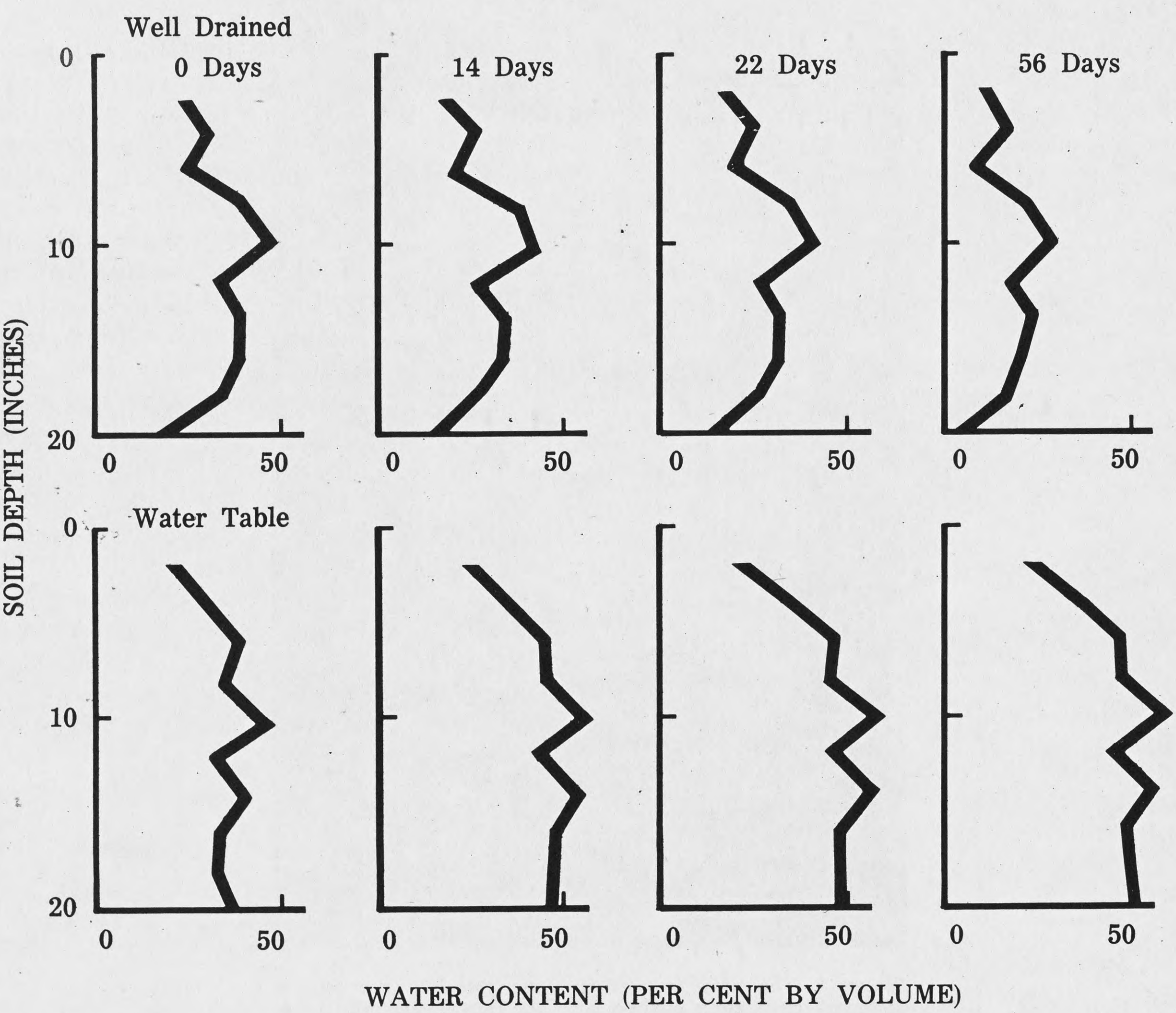

Figure 4. Soil moisture distribution for 4 times for Hecla soil cropped to soybeans. Soybeans were planted on day 0.

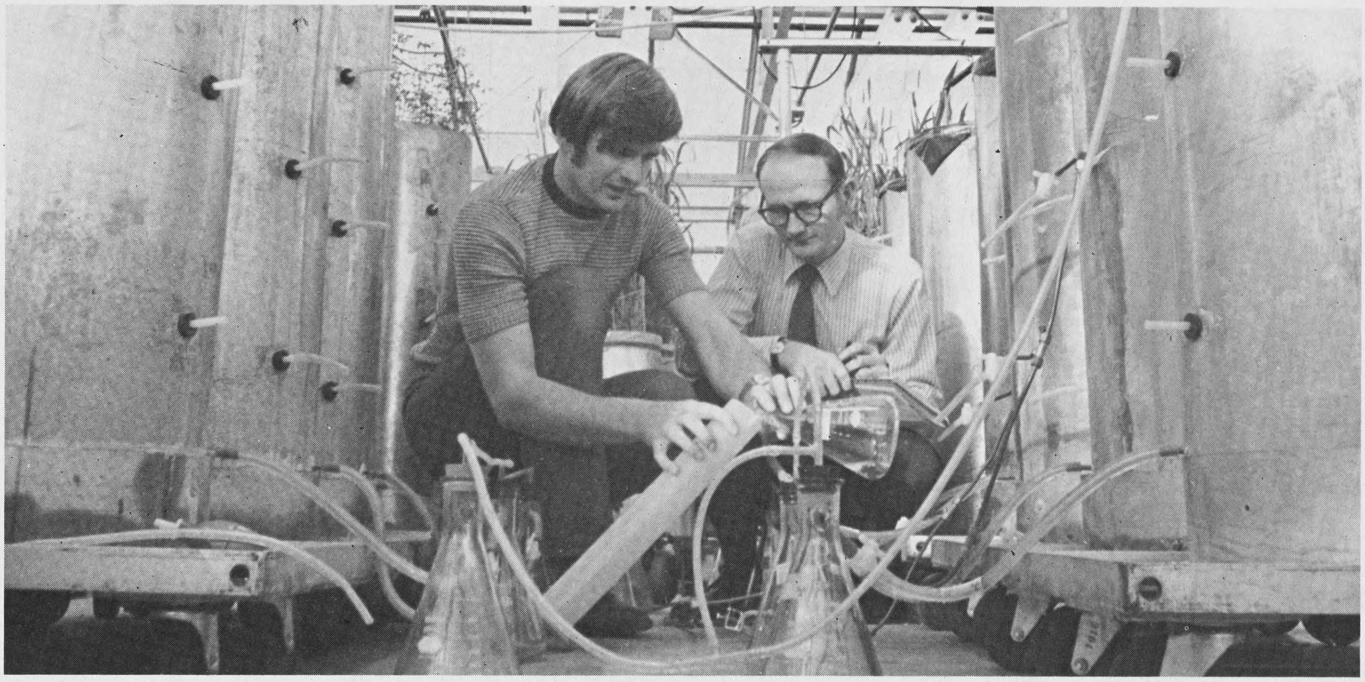

Figure 5. Two rows of soil cores resting on dollies equipped with swivel wheels. Drainage water is collected for each core and analyzed for the desired solutes.

illustrated in data collected for soybeans. Soybeans were planted in undisturbed cores of Hecla fine sandy loam 22 inches high and 8 inches in diameter. Column 2A was well drained while a water table was maintained 20 inches below the soil surface for Column 2B. Identical amounts of irrigation water were applied at the soil surface for each treatment at weekly intervals. Figure 4 shows the soil water distribution throughout the profile for columns 2A and 2B initially, and immediately before irrigation at three other dates. Column 2A showed a decrease in water content with depth observed after the 56th day at each sampling date. No decrease in water content with soil depth was observed for column 2B.

The phenotypic expression of the soybeans was similar for both treatments. Water moved upward from the water table in column 2B to replenish that water which was extracted by the plant roots and which was lost to evaporation from the soil surface. In fact, the soil surface remained moist at all times; more than 20 inches of water moved upward from the water table and evaporated at the soil surface. The irregular shape of the water content distribution curves with depth are effected by variations in bulk density and soil texture with depth.

3. Solute Movement

The movement of water-soluble salts in soils is intimately related to water movement. Water moving upward from a water table with subsequent evaporation at the soil surface can effect a concentration of salt(s) at the soil surface. On the other hand, water entering the soil surface from precipitation, runon, or irrigation tend to move salts downward in the soil profile. If excess water drainage is allowed, some movement of salts into the drainage water may occur. Several investigations are currently in progress which deal with solute movement. Figure 5 shows drainage water from the soil cores being collected in one such study. After the volume of water is recorded, the water is analyzed for solutes.

SUMMARY

A gamma-radiation attenuation unit was designed and built for monitoring changes in soil water content and its distribution in soils. The technique does not require destructive samples of the soil-plant system. Usefulness of the technique in research is limited only by the researcher's imagination. Applications for which the gamma radiation attenuation unit is currently being used are given.

References

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