Methods (Klute, A., ed). Agronomy Series No. 9. Am. Soc. Agronomy, 2nd edition, pp. 493-544.

Gurr, C.C. 1959. Use of gamma rays in measuring water content and permeability in unsaturated columns of soil. Soil Sci. pp. 224-229.

Mckim, H.L., J.E. Walsh and D.N. Arion. 1980. Review of techniques for measuring soil moisture in situ. United States Army Corps of Engineers, Cold Regions Research and Engineering Lab., Special Report 80-31.

Nofziger, D.L. 1978. Errors in Gamma-ray measurements of water content and bulk density in nonuniform soils. Soil Sci. Soc. Am. Proc., Vol. 42. pp. 845-850.

Nuclear Magnetic Resonance

1. **Description:**

With this technique, water in the soil is subjected to both a static and an oscillating magnetic field at right angles to each other. A radio frequency detection coil, turning capacitor, and electromagnet coil are used as sensors to measure the spin echo and free induction decays. Nuclear magnetic resonance imaging can discriminate between bound and free water in the soil.

2. **Measured Parameter:** Volumetric water content

3. **Response Time:** < 1 min.

4. **Disadvantages:** Same as for neutron scattering

5. **Advantages:** Same as for neutron scattering

6. **Related Literature:**

Anderson, S.H. and C.J. Gantzer. 1987. Determination of soil water content by X-ray computed tomography and NMR imaging. International Conference on Measurement of Soil and Plant Water Status. Centennial of Utah State Univ., pp. 239-246.

Paetzold, R.F., A.D. Santos and G.A. Matzkanin. 1987. Pulsed nuclear magnetic resonance instrument for soil-water content measurement: sensor configurations. Soil Sci. Am. J. 51:287-290.

Stafford, J.V. 1988. Remote, non-contact and in-situ measurement of soil moisture content: a review. J. Ag. Eng. Res. 41:151-172.

Tollner, E.W., J.M. Cheshire, Jr. and B.P. Verma. 1987. X-ray computed tomography and nuclear magnetic resonance for soil systems. International Conference on Measurement of Soil and Plant Water Status. Centennial of Utah State Univ., pp. 247-254.

ELECTROMAGNETIC TECHNIQUES

Resistive Sensor (General)

1. **Description:**

Electromagnetic techniques include methods that depend upon the effect of moisture on the electrical properties of soil. Soil resistivity depends on moisture content; hence it can serve as the basis for a sensor. It is possible either to measure the resistivity between electrodes in a soil or to measure the resistivity of a material in equilibrium with the soil. The difficulty with resistive sensors is that the absolute value of soil resistivity depends on ion concentration as well as on moisture concentration. Therefore, careful calibration is required for these techniques.

2. **Measured Parameter:**

Soil water potential aided by electrical resistance measurements

3. **Response Time:** Instantaneous

4. **Disadvantages:**

- Calibration not stable with time and affected by ionic concentration
- Cost of equipment to generate signal and readout system is high but could decrease with new solid-state technology

5. **Advantages:**

- Theoretically, can provide absolute soil water content
- Can determine water content at any depth
- Sensor configuration can vary in size so sphere of influence or measurement is adjustable