3.6 Soil moisture

The two main indexes of soil moisture are volumetric water content θ [m^3m^{-3}] and matric potential Ψ [Pa]. The former is the volume of water as a fraction of the total volume of soil, which is used to obtain an unsaturated diffusion coefficient of soil water. The latter is often referred to in discussions of water absorption by plant roots and soil water movement. There are various sizes of pores in soil. Water caught in smaller pores requires more energy to be extracted. Thus, when soil water is released, the water in large pores is the first to go out. The matric potential represents the amount of energy required for soil pores to hold water in capillary action and adsorption or the amount of energy required by plant roots to draw water in. The value is positive when the soil water is at saturation and negative otherwise. The matric potential per unit volume is expressed in Jm^{-3} = Nm^{-2} = Pa. Hydraulic head ($Jkg^{-1}m^{-1}s^2$ = m), which is a specific measurement of the amount of water energy per unit weight converted into the height of water column, is often referred to as a simple presentation of matric potential. One meter of hydraulic head corresponds to 9.86 hPa.

Other indexes of soil moisture include water content Θ [$kgkg^{-1}$] and saturation ratio η [m^3m^{-3}]. They are obtained from Equations 3.6-2 and 3.6-3, respectively. Soil consists of water, air and soil particles, or a liquid phase, a gaseous phase and a solid phase. The combined volume of the liquid and gaseous phases is the total pore volume.

$$\theta = \frac{V_r}{V_r + V_s + V_a} = \frac{W_r}{V_r + V_s + V_a} \quad (3.6\text{-}1)$$

$$\Theta = \frac{W_r}{W_s} \quad (3.6\text{-}2)$$

$$\eta = \frac{V_r}{V_r + V_a} \quad (3.6\text{-}3)$$

Here, V: volume [m^3], W: weight [g], r: liquid phase, s: solid phase and a: gaseous phase.

Types of instruments

Instruments for measuring the volumetric water content in soil include time domain reflectrometry (TDR) moisture meters such as the CS616-L, produced by Campbell Scientific Inc., US (Fig 3.6-1). On the principle that the permittivity of soil fluctuates according to the volumetric water content, the TDR moisture meter measures the permittivity of soil by the reflection of high-frequency electromagnetic waves. The TDR moisture meter is capable of measuring a wide range of average volumetric water contents for most soil layers as far as the probe reaches. The instrument, however, is susceptible to variations in temperature and soil salinity, which cause some errors. Low-priced permittivity moisture meters whose measurements are based on static capacitors (e.g., EC-5, Decagon Devices, Inc., US, Photo 3.6-1), which have become distributed recently, have similar problems with temperature and soil salinity. The length of the sensing unit varies between sensors, ranging from 5 cm to 1 m. They need to be used properly depending on soil sections.

With the aim of measuring the matric potential, a tensiometer (Photo 3.6-2) is used. The unglazed porous cup, which is filled with deaerated water, is buried to the measuring depth in an augured hole and exposed to the surrounding soil water. The pressure sensor measures the force with which water in the cup is attracted to the surrounding water.

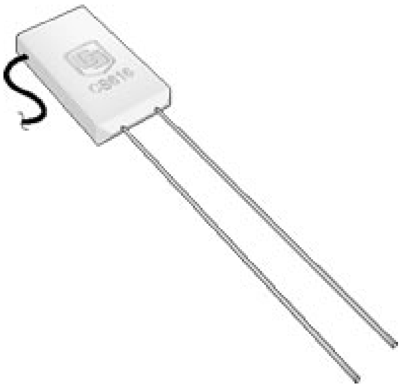

Fig. 3.6-1 TDR moisture meter CS616-L, Campbell. (Illustration: courtesy of Campbell Scientific Inc.)

Photo 3.6-1 Permittivity moisture meter EC-5, Decagon. (Photograph: courtesy of Decagon Devices, Inc..)

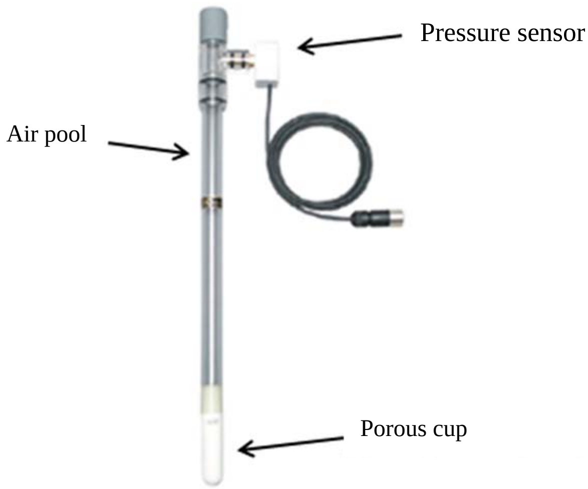

Photo 3.6-2 Tensiometer DIK-3000 series, Daiki Rika Kogyo.
(Photograph: courtesy of Daiki Rika Kogyo Co., Ltd.)

Measuring method

In principle, soil moisture sensors are installed at the same points where soil temperature is measured. In selecting the depth for monitoring soil water flux, water conditions in association with plant roots need to be fully taken into account. For example, in the evergreen forest of the Forestry and Forest Products Research Institute in Kompong, Thom Province, Cambodia, tree roots extend to nearly 2 m below the surface. At this site, observations are carried out at depths of 20, 50, 100, 150, 200 and 250 cm. Because the soil environment is never spatially uniform, it is recommended to repeat observations both area-wise and depth-wise as thoroughly as possible.

The sensing unit of a volumetric water content sensor and the porous cup of a tensiometer should be inserted into soil deep enough so as not to leave a gap at the base. To install the unit in a deeper section, soil is excavated in profile. The unit is inserted horizontally (Photo 3.6-3) and then the soil is recovered. To avoid soil disturbance, a vertical hole is dug to a designated depth with an auger. Then, a sensing unit attached to the tip of an extension rod is inserted into the hole. Any gap around the sensing unit and the porous cup should be filled with soil, because water may otherwise flow into the gap during heavy rainfall.

Photo 3.6-3 Soil profile created for the installation of a soil moisture meter EC-5. (Terrestrial Environment Research Center, University of Tsukuba, Photograph: courtesy of Shinichi Iida, FFPRI)

Caution is required to avoid breaking the porous cup of a tensiometer when it experiences stress while being inserted into soil. As the water in the tensiometer air pool gradually lessens, the air pool needs to be re-supplied with water, when necessary, so that it won’t become empty. When supplemented, water in the porous cup is opened up to the atmosphere and it takes one to 24 hours for the sensor to resume a correct value. Caution should be exercised so as to avoid damaging the sensor under excessive pressure when the air pool is capped and installed. The above-ground components, including the pressure sensor, should be shaded from the sun. If they are directly exposed to sunlight and their temperature fluctuates, air expands/contracts in the air pool and temperature drift occurs in the sensor output, which causes significant measurement errors. If the water in the tensiometer freezes, the sensor may stop operating. During the freezing season, observation needs to be suspended, after water is discharged.

With the help of the following soil water characteristic curve equation, the volumetric water content and the matric potential are mutually convertible.

$$\Psi = c_1 \left(\frac{\theta}{\theta_{sat}}\right)^{c_2} \qquad (3.6\text{-}4)$$

Here, θ_{sat} represents the saturated volumetric water content [m^3m^{-3}], and c_1 and c_2 are constants that can be obtained by the pressure plate method using a pressure plate dehydrator. In the pressure plate method, the lower section of a collected soil sample is exposed to the atmosphere while the upper section is subjected to high pressure, and soil water content is reduced by the pressure difference.

Calibration

The relationships between the volumetric water content and other parameters that are measured directly in soil by a sensor, such as neutron transmittance, electric resistance, thermal conductivity and permittivity, differ a great deal depending on soil components and constituents. Values put out by a soil moisture meter should not be fully trusted but should be corrected with the results obtained by the oven method.

Soil samples must be collected under various wet and dry soil conditions so that a wide range of soil water contents can be obtained. Sampling tubes of 100 cc and 400 cc should be used. After a sample is weighed, it is put in an oven at a temperature of 105 °C so that the water can evaporate. The volumetric water content can be calculated by dividing the weight reduction [g] by the volume of the sampling tube [cm^3]. Comparisons are made between the volumetric water content obtained by the oven method and the measurements made by the sensor to find an approximation. By putting a sensor observation value into the approximation, the volumetric water content can be figured out with reasonable accuracy.