Soil water status: content and potential

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The state of water in soil is described in terms of the amount of water and the energy associated with the forces which hold the water in the soil. The amount of water is defined by water content and the energy state of the water is the water potential. Plant growth, soil temperature, chemical transport, and ground water recharge are all dependent on the state of water in the soil. While there is a unique relationship between water content and water potential for a particular soil, these physical properties describe the state of the water in soil in distinctly different manners. It is important to understand the distinction when choosing a soil water measuring instrument.

Water content

Soil water content is expressed on a gravimetric or volumetric basis. Gravimetric water content (θg) is the mass of water per mass of dry soil. It is measured by weighing a soil sample ($mwet$), drying the sample to remove the water, then weighing the dried soil ($mdry$).

$$\theta_g = \frac{m_{water}}{m_{soil}} = \frac{m_{wet} - m_{dry}}{m_{dry}}$$

Volumetric water content (θv) is the volume of liquid water per volume of soil. Volume is the ratio of mass to density (ρ) which gives:

$$\theta_v = \frac{volume_{water}}{volume_{soil}} = \frac{\dfrac{m_{water}}{\rho_{water}}}{\dfrac{m_{soil}}{\rho_{soil}}} = \frac{\theta_g * \rho_{soil}}{\rho_{water}}$$

Soil bulk density ($\rho bulk$) is used for $\rho soil$ and is the ratio of soil dry mass to sample volume. The density of water is close to 1 and often ignored. Another useful property, soil porosity (ε), is related to soil bulk density as shown by the following expression.

$$\varepsilon = 1 - \frac{\rho_{bulk}}{\rho_{solid}}$$

The term $\rho solid$ is the density of the soil solid fraction and is approximated by the value 2.6 g cm^{-3}.

A simple data set is given at the top of the following column as an example. A sample of known volume was weighed before and after oven drying at 105°C for 24 hours.

mwet	94 g
mdry	78 g
sample volume	60 cm^3

$$\theta_g = \frac{m_{water}}{m_{soil}} = \frac{94g - 78g}{78g} = 0.205\, g\, g^{-1}$$

$$\rho_{bulk} = \frac{m_{dry}}{volume} = \frac{78\,g}{60\,cm^3} = 1.3\ \ g\,cm^{-3}$$

$$\theta_v = \frac{\theta_g * \rho_{soil}}{\rho_{water}} = 0.267\,cm^3\ cm^{-3}$$

$$\varepsilon = 1 - \frac{\rho_{bulk}}{\rho_{solid}} = 1 - \frac{1.3\,g\,cm^{-3}}{2.6\,g\,cm^{-3}} = 0.50$$

The porosity of 0.50 defines the maximum possible volumetric water content. The measured θv value of 0.267 indicates the pore space is just over half-full of water. If the sample is from a 30-cm depth profile, there are 8 cm of water in the profile.

Water content measurement methods include gravimetric, as described above, neutron probe, time-domain reflectometry (TDR) and other dielectric permittivity sensitive devices such as the CS615.

Water content indicates how much water is present in the soil. It can be used to estimate the amount of stored water in a profile or how much irrigation is required to reach a desired amount of water.

Water potential

Water flux—the movement of water—occurs within the soil profile, between the soil and plant roots, and between the soil and the atmosphere. As in all natural systems, movement of a material is dependent on energy gradients. Soil water potential is an expression of the energy state of water in soil and must be known or estimated to describe water flux.

Water molecules in a soil matrix are subject to numerous forces. If no adhesive forces were present, the water molecules would move through the soil at the same velocity as in free air minus delays from collisions with the solid matter—much like sand through a sieve. Soil water potential accounts for adhesive and cohesive forces and describes the energy status of soil water.

The fundamental forces acting on soil water are gravitational, matric, and osmotic. Water molecules have energy by virtue of position in the gravitational force field just as all matter has potential energy. This energy component is described by the gravitational potential component of the total water potential. The influence of gravitational potential is easily seen when attractive forces between water and soil are less than the gravitational forces acting on the water molecule and water moves downward.

The matrix arrangement of soil solid particles results in capillary and electrostatic forces and determines the soil water matric potential. The magnitude of the forces depends on texture and the physical-chemical properties of the soil solid matter. Most methods for measuring soil water potential are sensitive only to the matric potential.

Soil water is a solution. The polar nature of the water molecule results in interaction with other electrostatic poles present in the solution as free ions. This component of the energy status is the osmotic potential.

Methods for measuring soil water matric potential include tensiometry, thermocouple psychrometry, electrical conduction (generically Buoyucous blocks), and heat dissipation such as the Campbell Scientific sensor model 229.

There is a unique relationship between water content and water potential for each soil. The soil water characteristic curves for three soils are depicted below. For a given water potential, the finer the soil texture the more water held in the soil. Coarse texture soils like sand consists mostly of large pores which empty of water when a relatively small force is applied. Fine texture soils have a broader pore size distribution and larger particle surface area. Consequently, a larger change in water potential is required to remove the same amount of water. Greater surface area means more water is adsorbed via electrostatic forces.

Soil Water Characteristic Curves