METER
ENVIRONMENT

ESTIMATING RELATIVE HUMIDITY IN SOIL—HOW TO STOP DOING IT WRONG

Contributors

Many people assume the soil is dry when it feels dry to the touch. This false assumption can lead to poor decisions such as storing steel drums of toxic waste in a desert soil. The following calculations illustrate why steel drums would corrode in any soil, even if that soil that feels dry.

ESTIMATING RELATIVE HUMIDITY IN SOIL SEEMS DIFFICULT, BUT IT ISN'T

It is possible to apply physics to estimate the relative humidity in soil. The energy required to create an infinitesimal volume of water vapor can be found using the first law of thermodynamics. For an adiabatic system

where dE is the energy required, p is the pressure, and dV is the volume change.

$$dE = -pdV$$

The Boyle-Charles law, which gives the pressure-volume relationship for a perfect gas, is

$$pV = nRT$$

where n is the number of moles of gas, R is the universal gas constant, and T is the Kelvin temperature. Rearranging terms and taking the derivative of both sides gives

$$dV = -\frac{nRT}{p^2}\,dp$$

This equation can be substituted for dV in the first equation, giving

$$dE = \frac{nRT}{p}\,dp$$

The total energy required to go from a reference vapor pressure, p_o (the vapor pressure of pure water) to the vapor pressure of the water in the soil, p is

$$E = nRT\int_{p_o}^{p} \frac{dp}{p} = nRT \;\ln\left(\frac{p}{p_o}\right)$$

Divide both sides by the mass of water. The left side then becomes the energy per unit mass of water in the soil, which we call the water potential. On the right side, the number of moles per unit mass is the reciprocal of the molecular mass of water, and the ratio of the vapor to the saturation vapor pressure is the relative humidity h_r so the final equation is

$$\Psi = \frac{RT}{M_w} ln(h_r)$$

Rearrange this and take the exponential of both sides, giving

$$h_r = exp\left(\frac{M_w\Psi}{RT}\right) = exp\;(7.3 \times 10^{-6}\Psi)$$

In the second version of the equation the molecular mass of water, the gas constant and the temperature (298K) have been substituted.

EVEN DESERT SOIL IS NOT DRY

This equation is used to find the range of expected humidities in soil. When soil is very wet, the water potential is near 0, so the humidity is exp(0) = 1. At the dry end, the soil is dried mainly by plant water uptake. Even desert soils support some vegetation. The soil near the surface will be dried by evaporation, but a few decimeters below the surface the lowest water potentials are those to which plants can dry them. The nominal permanent wilting point (lower limit of plant available water) is -1500 J/kg. Desert vegetation can extract water to lower potentials. If their lower limit is -2500 J/kg, then the humidity is

$$h_r = exp\,(7.3 \times 10^{-6} \times -\,2500) = 0.98$$

so the relative humidity in the soil is around 98%. Sagebrush can go lower than -2500 J/kg. Researchers have measured -7000 J/kg under it at the end of the growing season, but even that is around 95% humidity. The conclusion is that the humidity in any soil is always near saturation, except in a shallow evaporation layer near the surface.

The WP4C uses the principles discussed above to measure water potential in soil, plants, seeds, and other porous materials. It is also now possible to create a full soil moisture release curve using the WP4C and the HYPROP.

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