METER
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QUICK AND EASY DETERMINATION OF THE -15 BAR (PERMANENT WILT) WATER CONTENT OF SOILS WITH THE WP4C

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A soil moisture characteristic is a relationship between water potential and water content for a soil. Information from a moisture characteristic is frequently used to determine the plant available water from the soil. By convention, the upper limit of plant available water is taken as -0.033 MPa (-1/3 bar, pF 2.53)*. The lower limit is -1.5 MPa (-15 bar, pF 4.18)**.

The upper limit is too wet to be measured reliably by the WP4C PotentiaMeter since the resolution of the instrument is 0.05 MPa. The lower limit, often called the permanent wilting point, is easily and quickly determined using the WP4C. The purpose of this note is to outline a procedure that can be used to find the water content at -1.5 MPa.

It is easy to bring a soil to a predetermined water content, but much more difficult to prepare a sample at a given water potential. Because of this, we recommend that samples be prepared at predetermined water contents. Their water potentials are then measured with the WP4C, and the -1.5 MPa water potential is found mathematically. The -1.5 MPa water content is strongly dependent on the clay content of the sample, as shown in the following table. Table 1 gives silt and clay fractions, -1.5 MPa water contents and air-dry soil water contents for representative members of the 12 soil texture classes. It is important to point out that these are average values from many soils. They can serve as a guide, but many things in addition to texture can influence the -1.5 MPa water content, so any given soil may differ substantially from the values given in the table. If that were not the case, no measurement would be needed.

Texture	Silt	Clay	$W_{-1.5}$ (kg/kg)	W_{ad} (kg/kg)
Sand	0.05	0.03	0.008	0.003
Loamy Sand	0.12	0.07	0.015	0.005
Sandy Loam	0.25	0.10	0.045	0.015
Sandy Clay Loam	0.13	0.27	0.143	0.048
Loam	0.40	0.18	0.106	0.035
Sandy Clay	0.07	0.40	0.2074	0.068
Silt Loam	0.65	0.15	0.098	0.033
Silt	0.87	0.07	0.075	0.025
Clay Loam	0.34	0.34	0.174	0.058
Silty Clay Loam	0.58	0.33	0.166	0.055
Silty Clay	0.45	0.45	0.204	0068
Clay	0.20	0.60	0.234	0.078

Table 1. Representative silt and clay fractions and -1.5 MPa and air-dry water contents for the 12 soil texture classes

The procedure for preparing samples is as follows. Begin with air-dry soil (soil that has been exposed to the air for a sufficient time so that it is in moisture equilibrium with the air; air-dry soil looks dry). The soil water content is defined as the mass of water divided by the mass of dry soil. This definition can be used to obtain the following equation for determining the mass of water to add to a given mass of air-dry soil to get the desired water content:

$$M_{wa} = \frac{(w - w_{ad})M_{ad}}{1 + w_{ad}}$$

Equation 1

(1) Where M_{ad} is the mass of air-dry soil, w is the desired final water content, and wad is the air-dry water content of the soil (from Table 1). As an example, assume we would like to prepare a sample of silt loam at approximately the -1.5 MPa water potential using 100 g of air-dry soil. From Table 1, w_{ad} for silt loam is 0.033 kg/kg, and w = 0.098 kg/kg. The mass of water to add is, therefore

$$M_{wa} = \frac{(0.098 - 0.033)100g}{1 + 0.033} = 6.29g$$

To prepare the sample, 6.29 g of water are added to 100 g of air-dry soil, the sampled is thoroughly mixed and placed in a sealed container (sealed baby food jar or similar) overnight to equilibrate. At the end of the equilibration period, a subsample of the soil is placed in a sample cup and its water potential is determined with the WP4C.

If the stainless steel cups are used in the WP4C, this same sample on which water potential was determined can be weighed, oven dried at 105 °C, and reweighed to determine the water content on the sample. If the polyethylene cups are used, a separate subsample from the jar is dried using standard drying tins. The water content is computed as the mass of water (change in sample mass on drying) divided by the mass of the oven-dry soil (dry mass of the sample and container minus the mass of the container).

Extreme care is necessary, especially in coarse textured soils, to obtain accurate water content values. The accuracy of the -1.5 MPa water content determination is more likely to be limited by the accuracy of the water content measurement than by the water potential measurement.

Since moisture equilibration is the time-consuming part of the measurement process, it is wise to mix two or three samples at water contents around the estimated -1.5 MPa value and run them all at once to assure that there are enough data available to accurately determine the value. For the example given above, we might make a second sample with, say, 5.5 g of water added to 100 g of soil.

Having obtained the water content – water potential information for the soil sample, the -1.5 MPa value is obtained by extrapolation or interpolation. This is easy to do since the moisture characteristic, between about -1 MPa (pF 4.01) and oven dry (-1000 MPa, pF 7.01) is linear in pF or logarithm of water potential. From a single value of water content and potential near the wilting point, the -1.5 MPa or pF 4.18 water content can be computed from

$$w_{-1.5} = w_m \frac{\ln\left(\frac{-1000}{-1.5}\right)}{\ln\left(\frac{-1000}{\psi_m}\right)}$$

Equation 2

or

$$w_{4.2} = w_m \frac{7.01 - 4.18}{7.01 - pF_m}$$

Equation 3

Where w_m is the measured water content corresponding to the water potential $?_m$ or pF_m.

If two data values are available the calculation can be made without using the oven-dry value. The equations then become

$$w_{-1.5} = w_{m1} + (w_{m2} - w_{m1}) \frac{\ln\left(\frac{\psi_{m1}}{-1.5}\right)}{\ln\left(\frac{\psi_{m1}}{\psi_{m2}}\right)}$$

Equation 4

or

$$\theta_{4.18} = \theta_{m1} + (\theta_{m2} - \theta_{m1}) \frac{pF_{m1} - 4.18}{pF_{m1} - pF_{m2}}$$

Equation 5

To illustrate, assume we obtained the following data on a silty clay soil

w	MPa	pF
0.185	-3.32	4.53
0.233	-1.01	4.01

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Table 2. Silty clay soil data

Using Equation 2, we can compute

$$w_{-1.5} = 0.233 \frac{\ln\left(\frac{-1000}{-1.5}\right)}{\ln\left(\frac{-1000}{\psi_m}\right)} = 0.233\ \frac{6.502}{6.898} = 0.220\ kg/kg$$

which, again, is close to the other two values. Equation 5 gives the same result. One final point should be made. These water contents are expressed as mass of water per mass of dry soil, or gravimetric water content. The value obtained is independent of the soil density at these low potentials. The volumetric water content is, however, the quantity needed for determining plant available water, since, in the field, volume is the basis for computing water storage, not mass. It is easy to convert from gravimetric to volumetric water content. The equation is

$$\theta_{-1.5} = w_{-1.5} \frac{p_b}{p_w}$$

Equation 6

(6) Where $\theta_{-1.5}$ is the volumetric water content ($m^3 m^{-3}$), ρ_b is the soil bulk density and ρ_w is the density of water. One must, therefore, know the bulk density of the soil to compute the volumetric water content. A typical value for soil is 1.35 Mg/m^{-3}, so the volumetric water content is typically about 35% higher than the gravimetric water content.

NOTES

* pF is defined as the base 10 logarithm of the suction expressed in cm of water. To convert between MPa and pF, first convert MPa to cm of water. The conversion factor is 10200 cm/MPa. Ignore the negative sign since we can't take the logarithm of a negative number. Now take the base 10 logarithm to get pF. -1 MPa corresponds to pF 4.01.

** In the past, a pressure plate has been used to determine the -1.5 MPa water content, but a number of publications have shown that the hydraulic conductivity of samples on a pressure plate is too low for equilibration to occur at these potentials. For example, see Gee et al. (2002), *Vadose Zone Journal* 1:172-178. The WP4C and other similar vapor pressure instruments provide the only reliable means for obtaining the -1.5 MPa water content of a sample.

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