

*TOOLS AND TIPS FOR MEASURING THE
FULL SOIL MOISTURE RELEASE CURVE*



WP4C HYPROP

0 100 kPa
Decagon

100

WP4C

2005
HYPROP
測定装置

UMS
2010

HYPROP

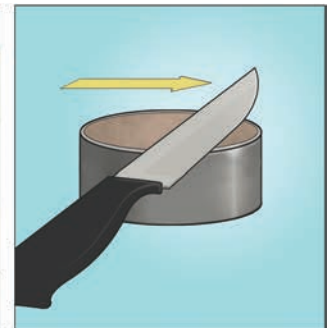
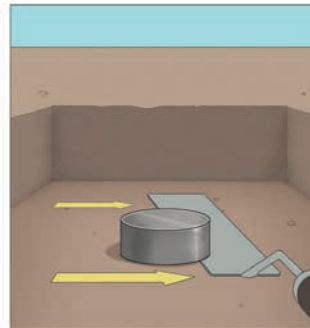
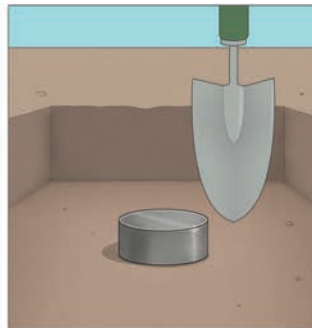
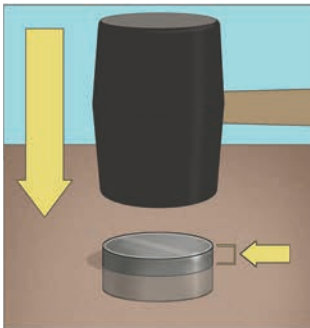
WP4C

WP4C HYPROP

-40 kPa

WP4C

-40 kPa



Using HYPROP for the Wet End of the Curve

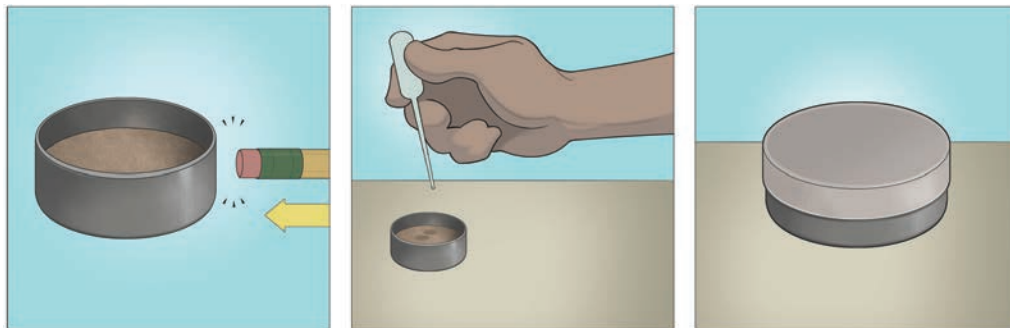
The HYPROP also utilizes a minimally disturbed sample which you should collect using a 250 ml sample ring. The sample can be saturated for 24 to 48 hours and run the following day. Once the HYPROP has been filled and started, it takes about a week, running unattended, to create a complete wet-end curve.



To learn how to use the HYPROP, start with the video at www.decagon.com/smrc

Sample Preparation: Coarse Textured Soils

The next step is to wet or dry the WP4C samples to different water contents. Coarse textured soils can be prepared using a wetting method. To do this, add one drop of water to the first sample, two to the second, 4 to the third, 6 to the fourth and so on. Make sure to mix the samples, cap them, and let re-equilibrate overnight. A typical curve is made using 10 - 15 WP4C samples.

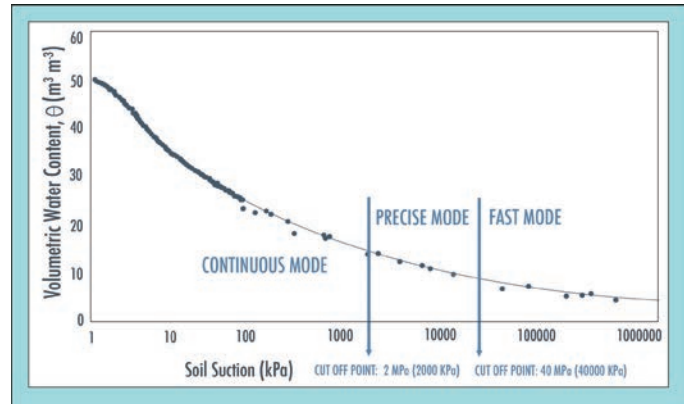


Sample Preparation: Fine Textured Soils

Finer textured soils such as clays and silt loams may show hysteresis and require a drying method for WP4C samples to improve the match between WP4C and HYPROP curves. Saturate the samples until they glisten and you see water beginning to pond on the surface. Then allow the samples to dry, capping them at intervals and allowing them to re-equilibrate to achieve different moisture contents.

Cut-Off Points for Precise and Continuous Modes

The WP4C's precise mode repeats water potential measurements on a sample until successive readings agree within 0.3 MPa (0.03 MPa for water potential greater than -40 MPa). This should be the default measurement mode. For wet-end samples (wetter than -2 MPa), use continuous mode with extremely careful measurement techniques. For samples drier than -40 MPa, fast mode is recommended. In this mode, the WP4C only takes one measurement to minimize errors due to water loss.



Getting Stable WP4C Measurements into Tensiometer Range

Measuring in the wettest range possible for a vapor pressure method (wetter than -2 MPa) requires an extremely careful experimental method.

For details on helpful experimental techniques, see "Measuring Water Potential into Tensiometer Range with the WP4C" later in this guide.

Prepare Data for HYPROP Fit

AquaLink allows you to annotate sample data as it is read. Along with information about the samples, you can include a column to note the moisture content of each sample.



Visit www.decagon.com/smr to see how AquaLink allows easy logging of data from your WP4C.



AquaLink is available as a free trial at www.decagon.com/aqualink

The screenshot shows the AquaLink 4 software interface. At the top, there are menu options: File, Edit, View, Device, Help. Below the menu is a toolbar with icons for Connect, Connect Via, Connect, Export, Import, and Chart. The main area displays a data table with the following columns: Date/Time, Device, Volume, Water Activity, Water Potential, °C, Travel Time, Sizer, Water Content, Type, Sensor, Photo, Event, Annotation, and Index. The table contains 15 rows of data, all from 2012-10-01 09:58:45 to 2012-10-01 10:04:25. The Water Content column has a value of 25 for all entries.

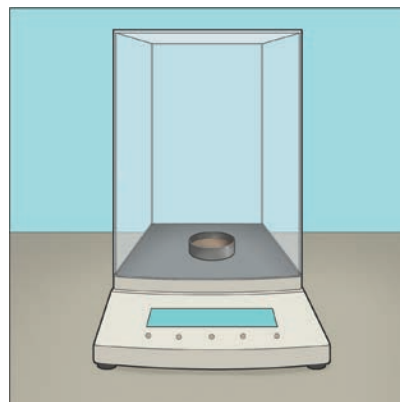
Date/Time	Device	Volume	Water Activity	Water Potential	°C	Travel Time	Sizer	Water Content	Type	Sensor	Photo	Event	Annotation	Index
2012-10-01 09:58:45	WP4C/L1	0.8987	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:58:50	WP4C/L1	0.8982	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:58:55	WP4C/L1	0.8984	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:00	WP4C/L1	0.8989	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:05	WP4C/L1	0.8984	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:10	WP4C/L1	0.8988	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:15	WP4C/L1	0.8993	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:20	WP4C/L1	0.8992	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:25	WP4C/L1	0.8991	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:30	WP4C/L1	0.8994	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:35	WP4C/L1	0.8993	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:40	WP4C/L1	0.8994	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:45	WP4C/L1	0.8994	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:50	WP4C/L1	0.8992	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 09:59:55	WP4C/L1	0.8992	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 10:00:00	WP4C/L1	0.8992	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 10:00:05	WP4C/L1	0.8993	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 10:00:10	WP4C/L1	0.8993	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 10:00:15	WP4C/L1	0.8993	-0.2463	-24.90				25					Sample 1 in Centrifuge	
2012-10-01 10:00:20	WP4C/L1	0.8993	-0.2463	-24.90				25					Sample 1 in Centrifuge	

Determine Moisture Content

Once the water potential has been measured, samples are weighed and put into the drying oven to find the moisture content. The weigh-dry-weigh method determines gravimetric water content, which must be converted to volumetric water content before making a moisture release curve using this equation:

$$\theta = \frac{\omega \times \rho_b}{\rho_w} \quad (1)$$

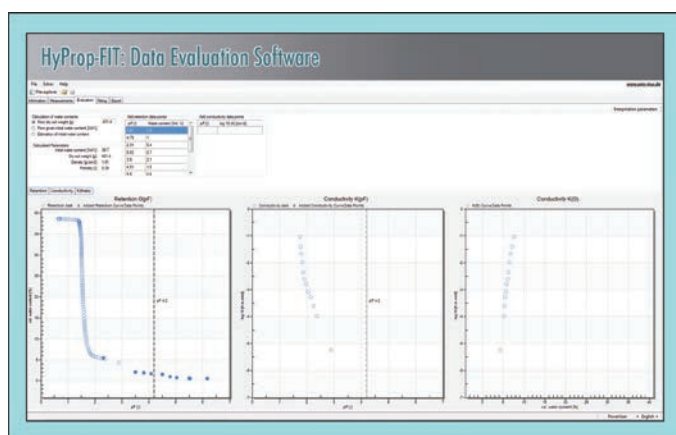
where w , is gravimetric water content, ρ_b , is soil bulk density and ρ_w is the density of water.



Note: The HYPROP determines a bulk density which can be used in this equation.

Combining the HYPROP and WP4C Data

Use HYPROP Fit software to combine data from both instruments into a single moisture characteristic curve. In HYPROP Fit, open the .bhd/.bhdX file of your measurement data from HYPROP Video.



WP4C data can be entered manually in the “Evaluation” tab under “Add Retention Points.” Be sure water contents have been converted from gravimetric to volumetric values before adding the data. Also, in soils with an EC higher than 0.2 dS/m, you should remove the osmotic potential component from the WP4C water potential readings in order to make a continuous curve.

For more details on this process, see “Measuring Matric Potential with the WP4C” in this guide.



HyProp Fit is available as a free download at www.decagon.com/hypropfit



Visit www.decagon.com/smrc to see how to transfer HYPROP and WP4C data into HYPROP Fit software.

Creating a Curve

Once all the data have been entered, go to the “Fitting” tab and select the model you would like to fit to your data. HYPROP Fit creates the complete moisture release curve for your soil. Parameters relating to the model you have chosen will be displayed along with statistics describing how well the model fits your data.

How to Measure Water Potential Up into Tensiometer Range with the WP4C

Advice from Dr. Doug Cobos, Decagon Research Scientist

Water potentials at or near field capacity are past the edge of the WP4C range. In order to get the best possible precision when measuring these moist samples, run the WP4C in continuous mode, log the data using a terminal emulator, and continue the measurement until you see a stable, fully equilibrated reading. Here's some real data to illustrate the point.

Time (Minutes)	Measured Water Potential (MPa)
3.5	-0.29
7.3	-0.25
11.0	-0.24
14.8	-0.23
18.6	-0.22
22.5	-0.22
26.3	-0.21
30.2	-0.21
34.1	-0.20
37.9	-0.20
41.8	-0.20
45.7	-0.20
49.5	-0.20

The data in Table 1 were collected on a -0.20 MPa KCl salt solution starting with an air dry (~-120 MPa) sensor block. If the WP4C had been configured in Fast mode, it would have reported the water potential of the first reading (-0.29 MPa), yielding an error of -0.09 MPa. In Precise mode, the WP4C waits for two consecutive readings to be within 0.03 MPa of each other, so it would have reported -0.24 MPa, yielding a -0.04 MPa error. However, if you are patient and your lab has decent temperature stability (more on temperature stability below), you can achieve precision to the 0.01 MPa level.

*Table 1:
Equilibration time when making vapor pressure measurements with -0.20 MPa KCl salt solution.*

Using the Linear Offset

If you use this technique carefully and are able to really dial in your precision, then you are half way there. We all know that it is possible to have great precision but poor accuracy, so our next step is to make our precise measurements accurate. The WP4C has a built-in offset adjustment sequence that you can use in conjunction with the 0.5 molal KCl standard that we provide to calibrate the instrument. This calibration sequence uses Precise mode to measure the water potential of the KCl standard and then adjusts all subsequent readings by the difference between the known and measured water potentials of the KCl solution. If you calibrate the WP4C using the built-in offset adjustment function, then I typically expect the wet end accuracy to be about ± 0.04 MPa due to the limitations of the Precise mode measurement of the KCl standard.

My strategy for really dialing in the accuracy is to run the KCl standard in continuous mode until an equilibrium value is reached. Then, I apply the offset between the known and measured water potential to all subsequent data during post processing in Excel or whatever program I am using for data analysis. When I did some careful evaluation of the wet end accuracy of the WP4C with some precision KCl solutions, I was able to achieve accuracy to about ± 0.02 MPa between -2.2 MPa and 0. Table 2 is an example data set. Note that all data were adjusted with the offset on the -2.238 MPa standard.

Known Water Potential (MPa)	Offset-Corrected Water Potential (MPa)	Absolute Error (MPa)
-2.238	-2.238	0.000
-1.346	-1.363	-0.017
-0.223	-0.238	-0.015
-0.132	-0.138	-0.006
-0.040	-0.053	-0.013
0.000	0.012	0.012

*Table 2:
Wet end accuracy of WP4C using precision KCl solutions.*

Use Stainless Steel Sample Cups

An additional important consideration when measuring moist samples is the type of sample cup that you should use. The disposable plastic cups are fine for dry samples, but not for wet samples. In the wet end, slight thermal gradients across the plastic sample cups can yield errors up to 0.05 MPa. The stainless steel cups have high enough thermal conductivity to become isothermal and prevent these errors. It is also important that you calibrate the instrument using the stainless steel cups if you are going to use them for wet end measurements.

Protect from Temperature Gradients

If you are measuring dry samples, small fluctuations in the sample temperature won't be noticeable, but if you are measuring in the wet end, these fluctuations can affect your repeatability, precision, and accuracy. The WP4C has internal temperature control to ensure thermal stability of the sample. This works quite well under most conditions. However, if there are rapid swings in the ambient temperature, the temperature stability can suffer.

I'll give you an example of the type of rapid temperature fluctuation that can affect a measurement. In my office, the most convenient place to set up the WP4C for long term measurements happens to



be directly in line with an HVAC vent. When the air conditioner turns on, there is enough cold air flow to cool the case of the WP4C about 1.5°C in less than 5 minutes. This type of temperature disturbance is enough to induce about 0.05 MPa error into the measurement. To help ensure temperature stability, I have placed the WP4C in a simple cardboard box with a large vent hole in the box at the rear of the WP4C to allow the heat from the WP4C to be exhausted out of the box. Note that the vent hole in the box is essential for good measurements. Without it, the box will heat up and the WP4C won't be able to control its temperature, which is worse than having it in the air conditioner stream.

Measuring Matric Potential with the WP4C

Moisture release curves created by the WP4C and HYPROP often match quite well, but sometimes they come out like the graph in Figure 1.

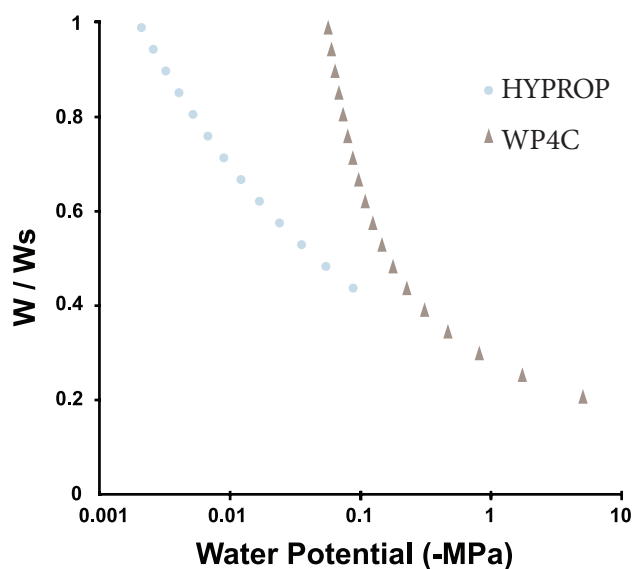


Figure 1: Moisture release curves generated by the HYPROP and WP4C of a silt loam soil with an EC of 1.4 dS/m.

The vertical axis is the degree of saturation, or ratio of water content to water content at saturation. The horizontal axis is water potential. It is clear that the two sets of results are not going to match. What is wrong? How can we fix it?

Vapor pressure methods, like the WP4C Dew Point Potentiometer, measure the sum of matric and osmotic potential, while tensiometers, like those in the HYPROP measure just matric potential. When the results of the two methods overlap, the osmotic component of the water potential is near zero. The osmotic component comes mainly from salts dissolved in the soil solution, and in soils with significant salt concentrations, the WP4C results will be like those in Figure 1.

If we knew the osmotic potential we could subtract it from the WP4C reading and obtain the matric potential. The result should match the HYPROP data. Fortunately it is relatively easy to determine the osmotic potential.

Figure 2 shows a more complete picture of the matric, osmotic and total potential of a silt loam soil. We assume the soil has a saturation extract EC of around 1.4 dS/m. We see that the total potential is dominated by the osmotic potential in the wet range, and by the matric potential in the dry range. We would be justified in just extending the HYPROP data in Figure 1 with a smooth curve to meet the WP4C

curve at around -3 MPa. If we want to do something more quantitative, though, we can calculate the values of the osmotic potential and subtract them from the total potentials.

If we keep the amount of salt in the soil constant (use distilled water to wet the soil and evaporation to dry it) we can approximate the osmotic potential (MPa) of the saturation extract from (USDA Handbook 60)

$$\psi_{os} = -0.036\sigma_s \quad (2)$$

where σ_s is the electrical conductivity of the saturation extract in dS/m.

At other water contents the osmotic potential is

$$\psi_o = \psi_{os} \frac{w_s}{w} \quad (3)$$

Here w is the gravimetric water content of the soil and ψ_s is the water content at saturation (or the water content at which we measured ψ_{os}). We could get ψ_{os} from electrical conductivity measurements, but it is easier to just measure it with the WP4C. Saturate a sample and measure its water potential and temperature. Since the sample is saturated, its matric potential is zero, so the measurement you get is the osmotic potential. Use ψ_{os} and ψ_s from this experiment in eq. 3 to compute the osmotic potential at the other water contents of your samples, and subtract those values from the total potential given by the WP4C to get matric potential.

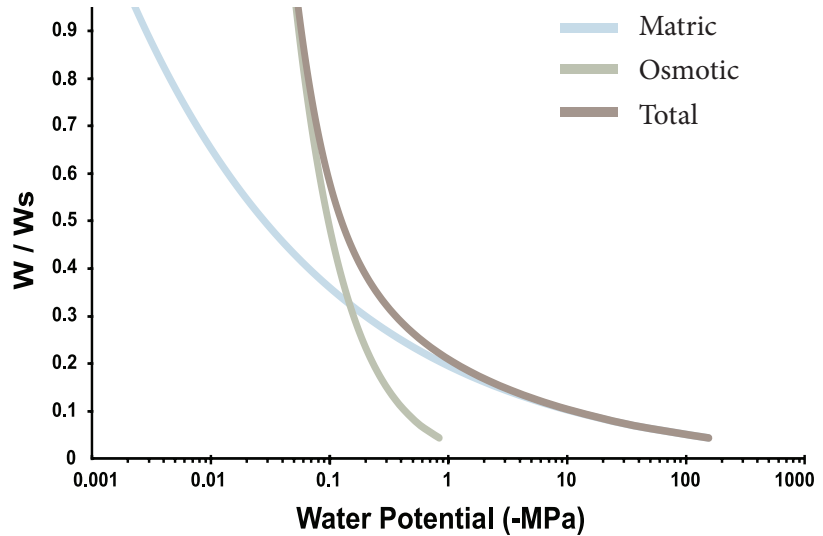


Figure 2:
A complete picture of the matric, osmotic and total matric potential of a silt loam soil.

Effects of Sample Disturbance on Soil Water Potential Measurements with the WP4C

Sample disturbance is often a concern when water potential is measured. Most researchers try to minimize sample disturbance and thereby ensure a more representative measurement. Sample disturbance, however, is inevitable. The purpose of this note is to assess the magnitude of sample

disturbance effects and relate them to the range of water potential of the soil sample. A soil is often modeled as a bundle of capillary tubes with a wide range of pore sizes. As shown in Table 3, a unique relationship exists between the water potential associated with a given pore size and the diameter of the pores. This relationship comes from the Young-Laplace equation, which relates the water potential of water beneath an air-water interface to the curvature of that interface.

	kPa	pF	Pore Diameter (μm)
	-1	1.01	290.08
	-10	2.01	29.01
Field Capacity	-33	2.53	8.79
	-100	3.01	2.90
	-1000	4.01	0.29
Perm. Wilt. Pt.	-1500	4.18	0.19
	-10,000	5.01	0.03
Air Dry	-100,000	6.01	
Oven Dry	-1,000,000	7.01	

Table 3:
Water potential units: MPa comparison to pore diameter and pF.

The water in the largest pores is the most loosely held, and is the first to be lost as the soil dries. As the soil becomes drier, the residual water is held in smaller pores. Eventually the capillary analogy breaks down, and the water is held mainly as adsorbed films on particle surfaces. The relationship between water potential and water content for a soil is called a “moisture release curve”, or “moisture characteristic”.

The soil moisture characteristic can be broken into three approximate ranges based on the forces that hold water in the soil:

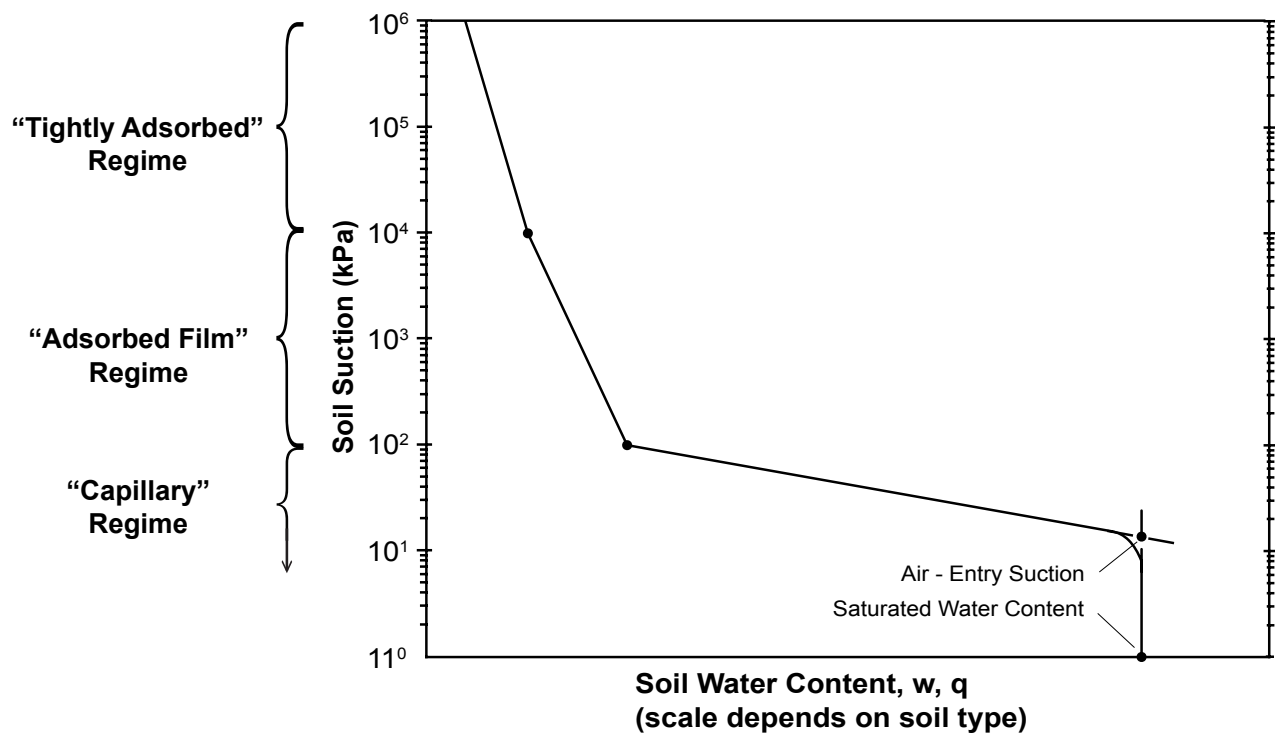


Figure 3:
Idealized soil moisture characteristic from Lu and Likos (2004) showing the three soil moisture retention regimes.

Tightly adsorbed: oven dry to $-10,000$ kPa
 Adsorbed films: $-10,000$ to -100 kPa
 Capillary water: -100 to 0 kPa

Soil disturbance and changes in bulk density mainly alter the sizes of the largest pores. Disturbance can therefore strongly affect the water content-water potential relationship of samples in the capillary range of potentials, but has a negligible effect on the water potential of samples in the tightly absorbed and absorbed film ranges. This is shown in Figure 4, from Box and Taylor (1962). They investigated the effects of bulk density on the moisture characteristic. Figure 4 shows that the change in density dramatically affects the matric potential when the soil is wetter than about -40 kPa but has little effect in drier soil. Campbell and Gardner (1971) obtained similar results.

The WP4C is accurate to ± 50 kPa in the wet range when used in precise mode, meaning that a measurement of -50 kPa has an accuracy of $\pm 100\%$. This measurement uncertainty is far larger than uncertainty due to density differences, so the effects of sample disturbance are likely negligible in this scenario.

Expert users of the WP4C can use continuous mode and extremely careful experimental method to increase accuracy to ± 25 kPa and essentially extend the functional measurement range of the WP4C further into the capillary water range. If this type of careful research is being done, errors from sample disturbance could become non-negligible and it is recommended to use minimally disturbed samples in the WP4C.

References

Box, J.E., and S.A. Taylor. (1962). Influence of soil bulk density on matric potential. Soil Sci. Soc. Amer. Proc. 26:119-122.

Campbell, G.S., and Walter H. Gardner (1971). Psychrometric Measurement of Soil Water Potential: Temperature and Bulk Density Effects. Soil Sci. Soc. Amer. Proc. 35:8-12.

Lu, N., and W. Likos (2004). Unsaturated Soil Mechanics. John Wiley and Sons, Hoboken, NJ USA.

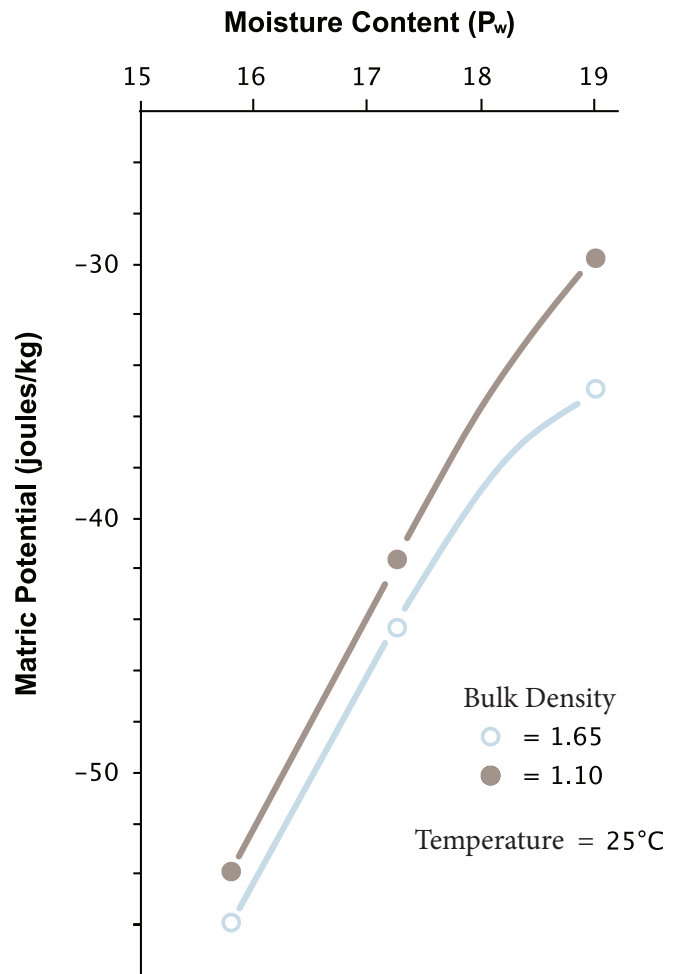
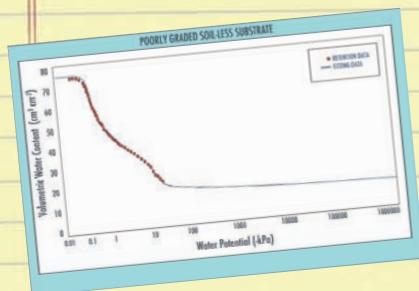


Figure 4
 Box and Taylor (1962) graph showing changes in matric potential due to differences in bulk density. Note that the units of J/kg are equivalent to units of kPa.

I've always felt a little dissatisfied with the moisture release curve data between 0 and 1000 kPa. The soil is losing half or more of its total water content, but if you're using pressure plates, as most of us are, the curve is based on only five data points.

Leaving aside all the issues surrounding pressure plates—how long it takes, how accurate it actually is—the fundamental issue is just this: you can only get five data points.

I just always wanted better resolution in this section. That's why I'm such a fan of the HyProp. Yes, it takes time to learn to use it, but once you're going, you can take a sample, wet it up, insert the tensiometers, plug it in, and watch a beautiful curve unfold over the course of a week or so.



This is a HyProp curve I made recently. It's a poorly graded soil-less substrate used in greenhouses. The HyProp gave me over 100 data points. As you can see, the result is much more interesting than you could have predicted if you were limited to just five points.

Add the breakthrough accuracy and range gains made on the WP4C and by using these two instruments together, you can finally get the kind of resolution you want over the full moisture release curve.



Don't get me wrong—measuring water potential at the edge of the range of these instruments can still be a challenge, but finally it's possible to get a complete, high resolution curve, and with much less effort and time than it used to take.

Visit our website, www.decagon.com/bettertogether or keep reading to see some of the techniques that make these curves possible.

