



# METER

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

### HOW TO CREATE A FULL MOISTURE RELEASE CURVE USING THE WP4C AND HYPROP

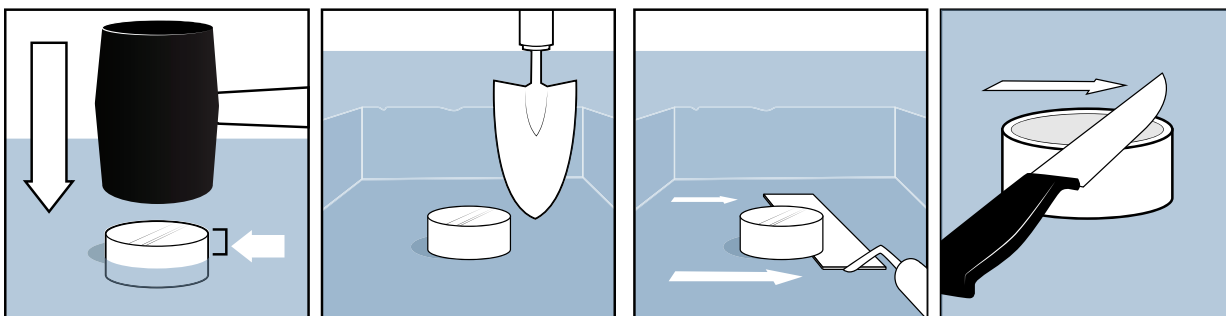
Creating a full moisture release curve is challenging. There is no single instrument capable of measuring the range of soil water potentials needed for a full curve, and historically, even those instruments capable of measuring part of the curve had limitations that affected the final results.

In the last several years, however, this has begun to change. In 2005, German instrument maker UMS introduced the HYPROP, an instrument capable of producing over 100 data points in the 0 to 100 kPa range. Then in 2010, METER made significant accuracy and range gains on the WP4C water potential meter which allow it to make good readings into tensiometer range.

Measuring water potential with the HYPROP is an art, and using the WP4C to make measurements into tensiometer range requires care and skill. But with good measurement techniques it is finally possible to get a complete, high-resolution soil moisture release curve. This application guide will teach the techniques needed to make these measurements.

#### COLLECTING SAMPLES

Collect samples for both the WP4C and the HYPROP. In samples drier than -40 kPa, sample disturbance does not contribute significantly to measurement uncertainty (see “Effects of Sample Disturbance on Soil Water Potential Measurements” later in this guide). In making the complete curve, however, measure samples wetter than -40 kPa using the WP4C, and use stainless steel sample cups to collect minimally-disturbed samples.

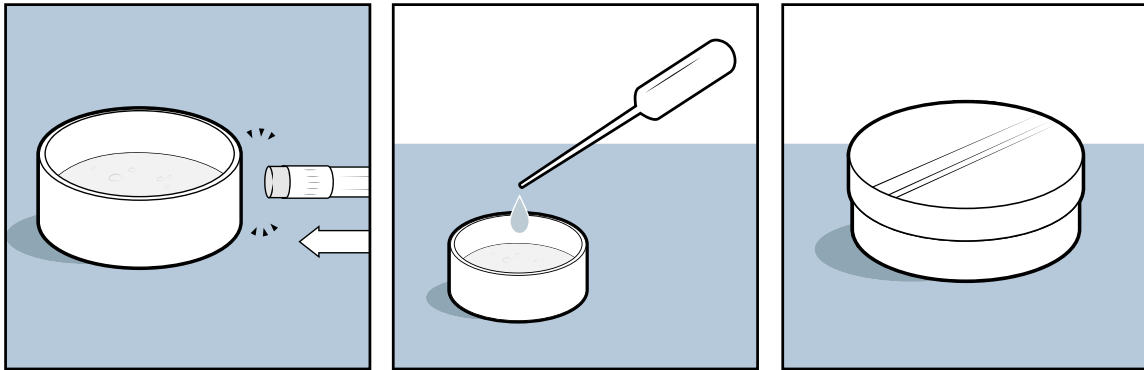


#### USING THE HYPROP FOR THE WET END OF THE CURVE

The HYPROP also uses a minimally-disturbed sample which should be collected 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.

#### SAMPLE PREPARATION: COURSE-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 1 drop of water to the first sample, 2 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.

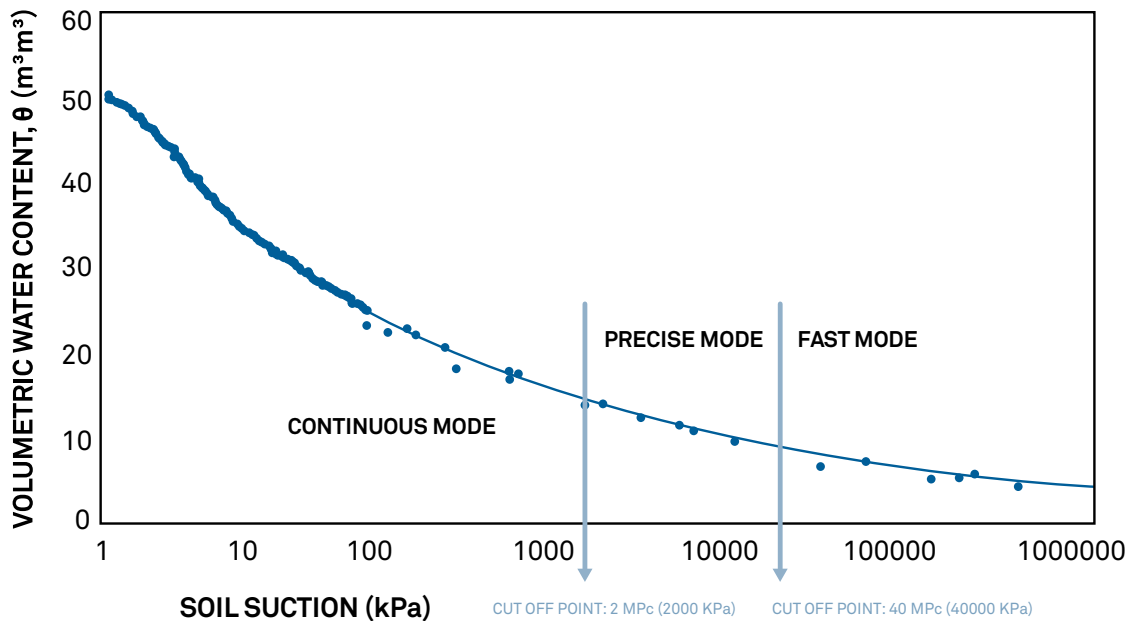


### SAMPLE PREPARATION: FINE-TEXTURED SOILS

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 water begins 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 the annotation sample data as they are read. Along with information about the samples, it is possible to include a column to note the moisture content of each sample.

## 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

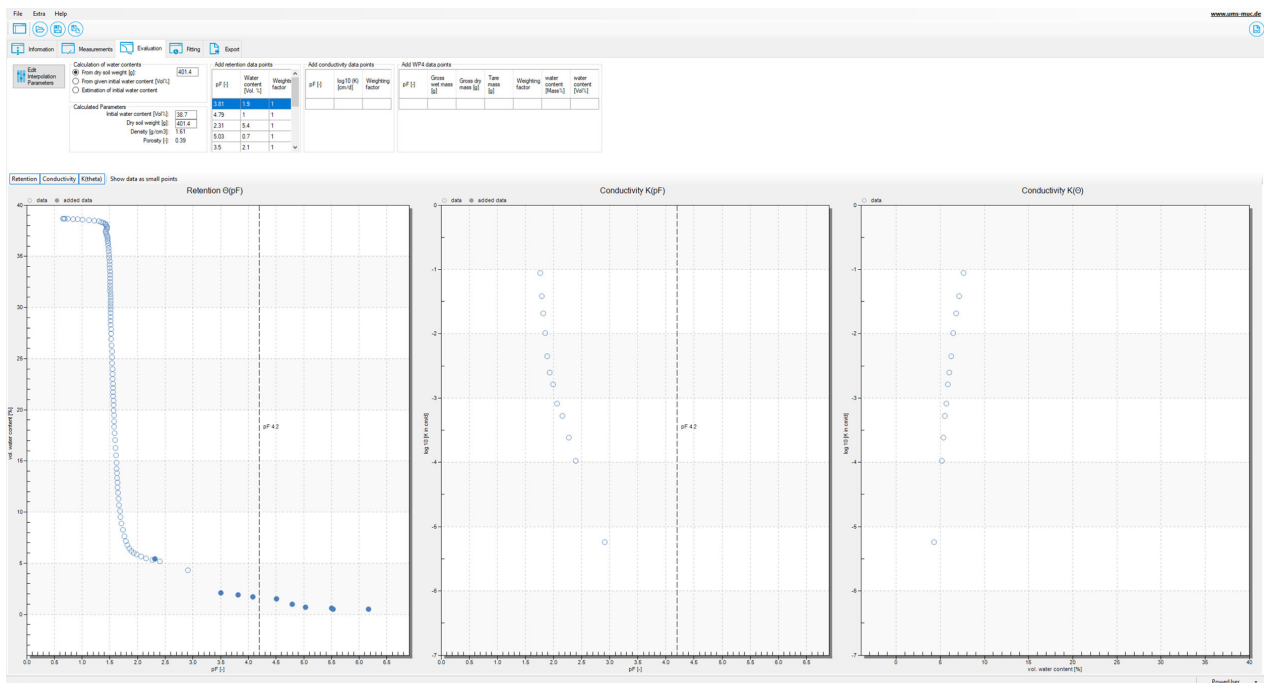
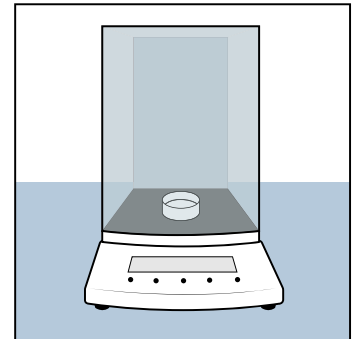
$$\theta = \frac{\omega \times \rho_b}{\rho_w} \quad \text{Equation 3}$$

where  $\omega$  is gravimetric water content,  $\rho_b$  is soil bulk density  $\rho_w$  and is the density of water.

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

## COMBINING THE HYPROP AND W4PC 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, 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.

## CREATING A CURVE

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

## HOW TO MEASURE WATER POTENTIAL UP INTO TENSIOMETER RANGE WITH THE WP4C

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 a stable, fully-equilibrated reading is seen. Here are some real data to illustrate the point.

The data in Table 1 were collected on a -0.20 MPa KCl salt solution starting with an air dry (approx. -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, with patience and a lab that has decent temperature stability (more on temperature stability below), it is possible to achieve precision to the 0.01 MPa level.

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

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

data during post processing in Excel (or other data analysis program). With careful evaluation of the wet end accuracy of the WP4C using precision KCl solutions, it is possible to achieve accuracy to about  $\pm 0.02$  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

### USING THE LINEAR OFFSET

Using this technique carefully and being precise is half the battle. It is possible to have great precision but poor accuracy, so the next step is to make the precise

measurements accurate. The WP4C has a built-in offset adjustment sequence that can be used in conjunction with the 0.5 molal KCl standard provided 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 calibrating the WP4C using the built-in offset adjustment function, expect the wet end accuracy to be about  $\pm 0.04$  MPa due to the limitations of the precise mode measurement of the KCl standard.

One strategy for achieving higher accuracy is to run the KCl standard in continuous mode until an equilibrium value is reached. Then apply the offset between the known and measured water potential to all subsequent

## USING STAINLESS STEEL SAMPLE CUPS

An additional important consideration when measuring moist samples is the type of sample cup to 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 to calibrate the instrument using the stainless steel cups if employing them for wet end measurements.

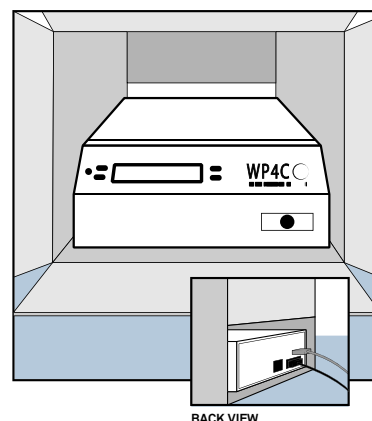
KNOWN WATER POTENTIAL (MPa)	OFFSET-CORRECTED WATER POTENTIAL (MPa)	ABSOLUTE ERROR (MPa)
-2.238	-2.238	0.000
-1.346	-1.363	-0.017
-0.223	-0.238	-0.015
-0.132	-0.138	-0.006
-0.040	-0.053	-0.013
0.000	0.012	0.012

Table 2 Wet end accuracy of WP4C using precision solutions

## PROTECT FROM TEMPERATURE GRADIENTS

If measuring dry samples, small fluctuations in the sample temperature won't be noticeable, but if measuring in the wet end, these fluctuations can affect 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.

Here's an example of the type of rapid temperature fluctuation that can affect a measurement. In an office, the most convenient place to set up the WP4C for long term measurements might 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, place 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 WATER 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.

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?

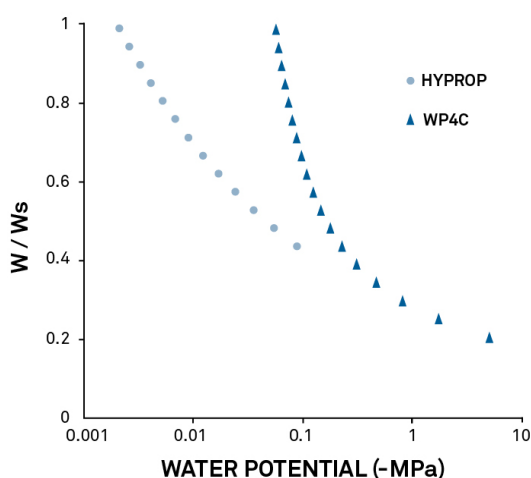


Figure 1 Moisture release curves generated by the HYPROP and WP4C of a silt loam with an EC of 1.4 dS/m

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. In soils with significant salt concentrations, the WP4C results will be like those in Figure 1.

If the osmotic potential is known, it is possible to 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. Assuming the soil has a saturation extract EC of around 1.4 dS/m, the total potential is dominated by the osmotic potential in the wet range and by the matric potential in the dry range. It is then

justifiable to extend the HYPROP data in Figure 1 with a smooth curve to meet the curve at around -3 MPa. To do something more quantitative, though, it is possible to calculate the values of the osmotic potential and subtract them from the total potentials.

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

$$\psi_{os} = -0.036\sigma_s \quad \text{Equation 1}$$

where  $\sigma_s$  is the electrical conductivity of the saturation extract in dS/m.

At other water contents the osmotic potential is

$$\psi_o = \psi_{os} \frac{w_s}{\omega} \quad \text{Equation 2}$$

Here  $\omega$  is the gravimetric water content of the soil and  $\psi_s$  is the water content at saturation (or the water content at which we measured  $\psi_{os}$ ). It is possible to get  $\psi_{os}$  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 obtained is the osmotic potential. Use  $\psi_{os}$  and  $\psi_s$  from this experiment in equation 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.

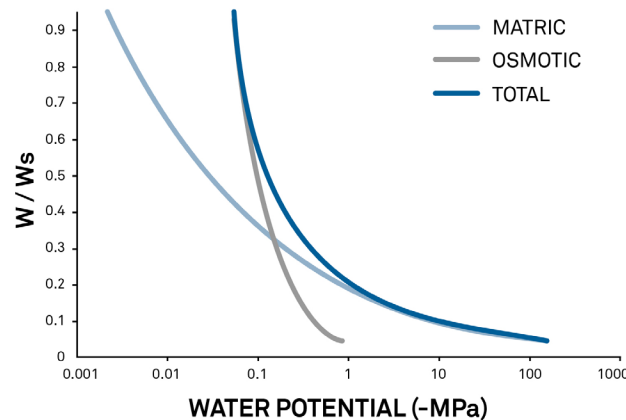


Figure 2 A complete picture of the matric, osmotic, and total matric potential of a silt loam soil

## EFFECTS OF SAMPLE DISTURBANCE ON SOIL WATER POTENTIAL MEASUREMENTS WITH THE WP4C

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

	kPa	pF	PORE DIAMETER (μm)
	-1	1.01	280.08
	-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
	-10000	5.01	0.03
AIR DRY	-100000	6.01	
OVEN DRY	-1000000	7.01	

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

equation, which relates the water potential of water beneath an air-water interface to the curvature of that interface.

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:

- 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 adsorbed and adsorbed 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.

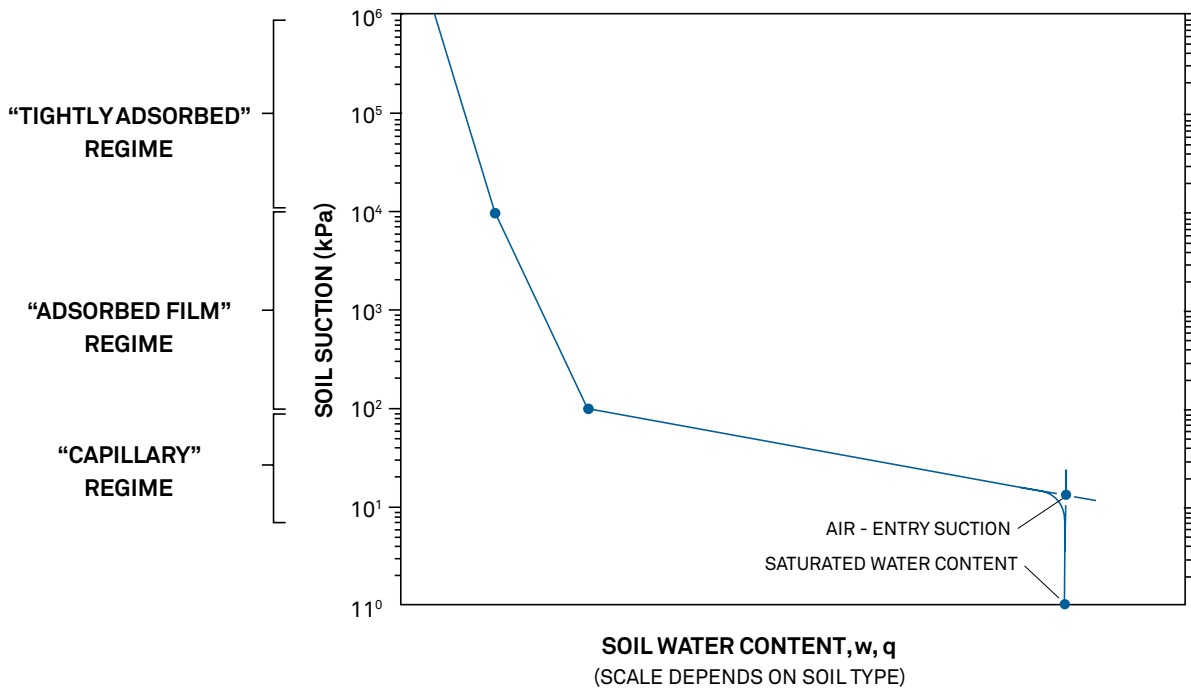
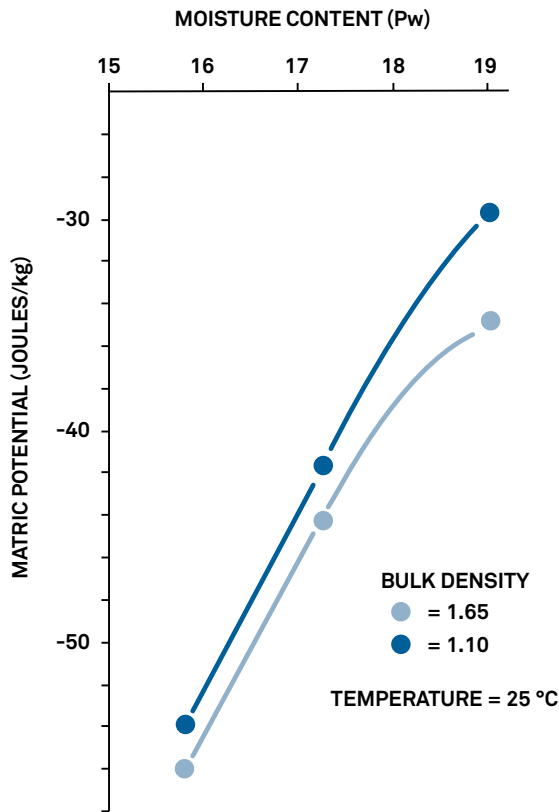


Figure 3 Idealized soil moisture characteristic from Lu and Likos (2004) showing the three soil moisture retention regimes

The WP4C is accurate to  $\pm 50$  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 methods to increase accuracy to  $\pm 25$  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.

Figure 4 Box and Taylor (1962) graph showing changes in matric potential due to differences in bulk density

Note: the units of J/kg are equivalent to units of kPa



## REFERENCES

Box, James E., and S. A. Taylor. "Influence of soil bulk density on matric potential." *Soil Science Society of America Journal* 26, no. 2 (1962): 119-122.

Campbell, Glen S., and Walter H. Gardner. "Psychrometric measurement of soil water potential: temperature and bulk density effects." *Soil Science Society of America Journal* 35, no. 1 (1971): 8-12.

Ning, Lu, and William J. Likos. "Unsaturated soil mechanics." *John Wiley & Sons Inc*, New Jersey (2004).