18557-00
11.2023

METER

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.

Measuring water potential in the wet range with the HYPROP and into the dry range with the WP4C 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 illustrate the techniques needed to perform these measurements.

Get the Researcher’s complete guide to water potential.

FACTORS TO BE CONSIDERED WHEN COMBINING HYPROP AND WP4C DATA

OSMOTIC VS. MATRIC POTENTIAL

In soils, the total water potential is the sum of four different components (Ψ_t): matric potential (Ψ_m), osmotic potential (Ψ_o), gravitational potential (Ψ_g), and pressure potential (Ψ_p). In a soil moisture release curve, two main components are active: matric and osmotic potential. The HYPROP measures matric potential only, and the WP4C measures matric potential and osmotic potential.

In soils with a significant salt concentration. the water potential component must be considered when combinging HYPROP and WP4C data. The osmotic potential will need to be determined and subtracted from the WP4C readings. Most soils have a lower salt concentration and won't need this adjustment.

HYSTERESIS

It is possible for one water content to have multiple water potentials. The progress of the retention curve depends on whether the measurement is based on a dry soil that is saturating (wetting curve) or a saturated soil that is drying (drying curve). At the same water content, the soil moisture tension on a drying curve will always be higher than on a wetting curve.

One reason for this phenomenon is the heterogeneity, or irregular sequence, of coarse pores and fine pores. Coarse pores drain faster than fine pores, but fine pores refill faster than coarse pores. Another factor that affects the progress of a soil moisture release curve is that air is trapped differently depending on the method and speed of pore saturation (Hartge, Horn 1999, 148ss).

Because of hysteresis, the method used for determining a water retention curve must be considered. When using the more time-consuming adsorption method, oven-dry material is saturated to the desired water content. In contrast, the more common desorption method (HYPROP) is based on the measurement of a drying soil. In order to replicate and combine measurement values generated by two different instruments, it is essential to choose the same method (Hartge, Horn, 1999, 148ss).

WHAT DOES THIS MEAN FOR COMBINING HYPROP AND WP4C MEASUREMENTS?

The HYPROP measurement is based on the evaporation method, where a saturated soil sample is placed on a scale and exposed to natural evaporation, which is on the drying portion of the curve (HYPROP User Manual). The WP4C measurement can be made by using either the wetting method or the drying method.

Because of hysteresis, combining wetting and drying curves results in curves that do not match. This case is illustrated by the two curves in Figure 1. At certain water contents, the retention data measured with HYPROP on the drying curve have higher water potentials than the WP4C-measured data on the wetting curve. To prevent this problem, use a drying method with the WP4C. This places the samples on the same drying curve as the HYPROP, as illustrated in Figure 2.

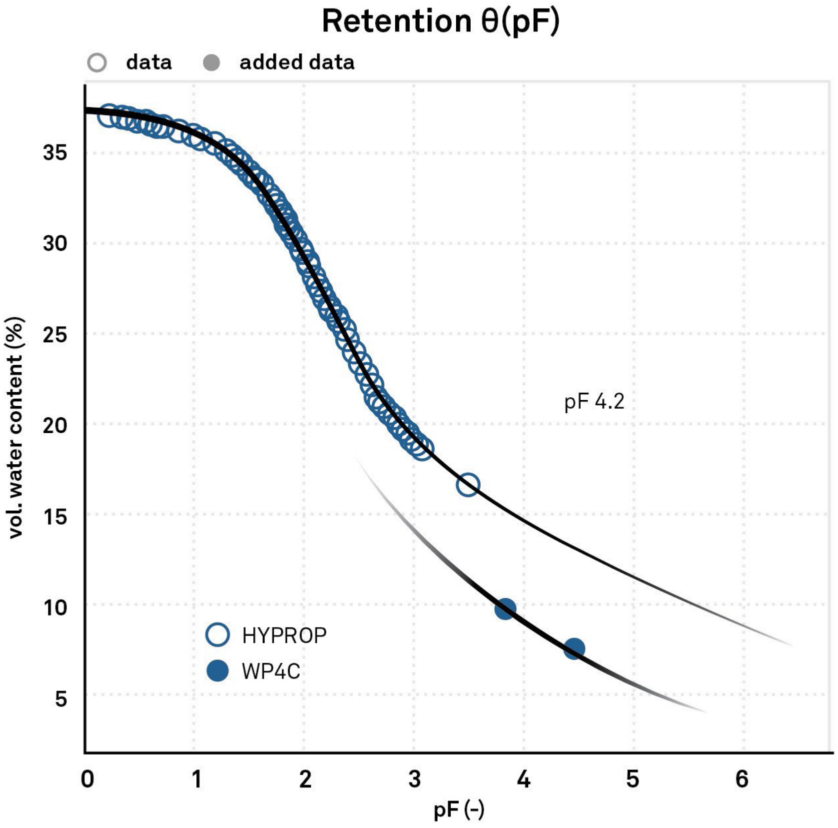


Figure 1 Combining wetting and drying curves results in curves that do not match

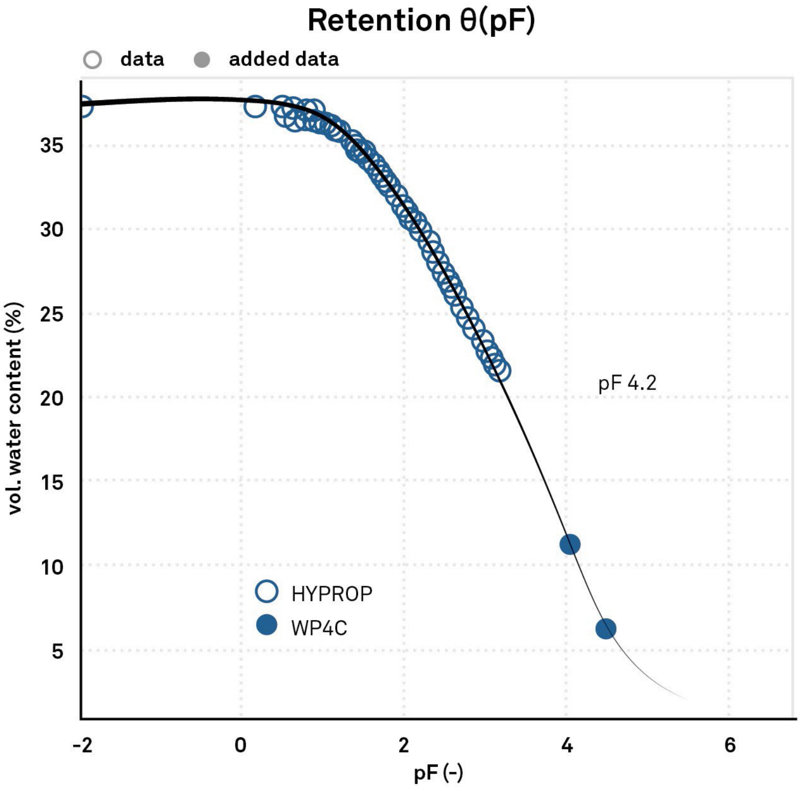


Figure 2 Using a drying method with the WP4C places the samples on the same drying curve as the HYPROP

WP4C MEASUREMENT ON A DESORPTION CURVE

There are two options for making a WP4C measurement on a desorption (drying) curve.

OPTION 1

The water content of the desired tension reading is defined, and the weight of the sample at that water content must be calculated. A disturbed sample is saturated beyond the defined water content, placed on a scale, and evaporated until reaching the calculated weight.

Disadvantage: This method is extremely time consuming, and if the calculated weight is missed, the sample must be resaturated.

OPTION 2 (RECOMMENDED)

At the end of the HYPROP measurement, WP4C samples are taken from the same soil sample.

The measurement is continued on the same drying curve as the HYPROP measurement, allowing for better pairing of data.

Option 2 is described step-by-step in the following section.

COLLECTING WP4C SAMPLES

1. Perform the HYPROP measurement until the second tensiometer shows the air entry, as indicated in Figure 3 (within the red circle). Waiting longer makes the WP4C samples too dry. Stopping significantly earlier may have the opposite effect. Therefore, it is up to the user to determine when (within the acceptable red circle) to obtain the data.

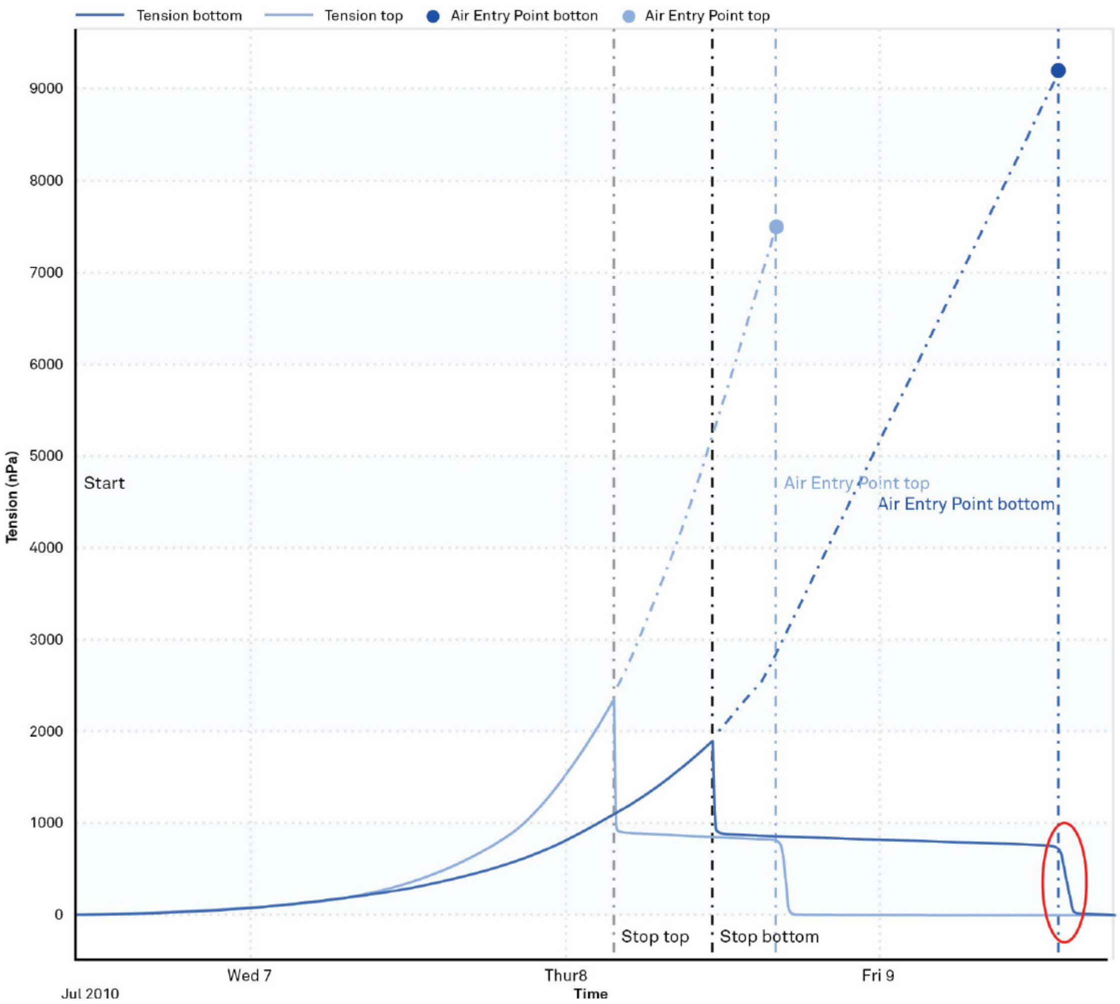


Figure 3 **Perform the HYPROP measurment until the second tensiometer shows the air entry**

2. After stopping the HYPROP measurement, remove the sampling ring (including the soil core) from the HYPROP device (see Figure 4). Perform all operations in a large drying pan to avoid losing any soil. In some cases, as with clay soils, it is not possible to separate the sample from the tensiometer shafts without wetting it before dismounting. If this happens, stop the HYPROP measurement after cavitation of the top tensiometer. Or, a second option for clay samples is to use drinking straw pieces around the tensiometer shafts that can slide off when removing the sample.

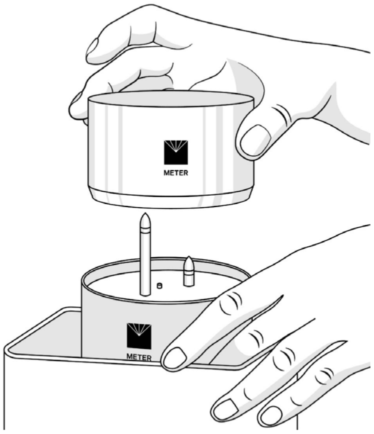


Figure 4 Removing the sampling ring

NOTE: For sandy soil samples, leave the sample on the HYPROP and collect the WP4C samples while removing the soil sample in layers. Collect samples following similar methods to step 4.

3. Prepare six WP4C sample cups to be filled with soil from the HYPROP core.

   Note the tare weight of the sample cups (Figure 5). Label each cup, and make note of which cup is used for each sample.

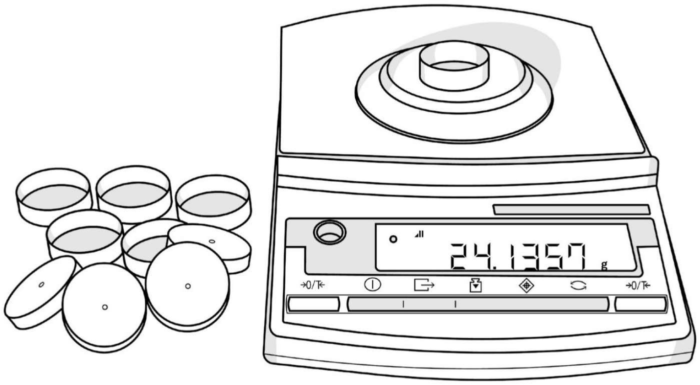


Figure 5 Note the tare weight of the sample cups

4. Take two WP4C samples from the top of the HYPROP soil sample core.

   Use a spoon or other suitable instrument to get enough soil material to fill the first two WP4C cups half full (Figure 6).

5. Seal the sample by placing the lid on the sample cup.

   If WP4C measurements will not be made soon after sampling, seal around the cup with tape to avoid evaporation

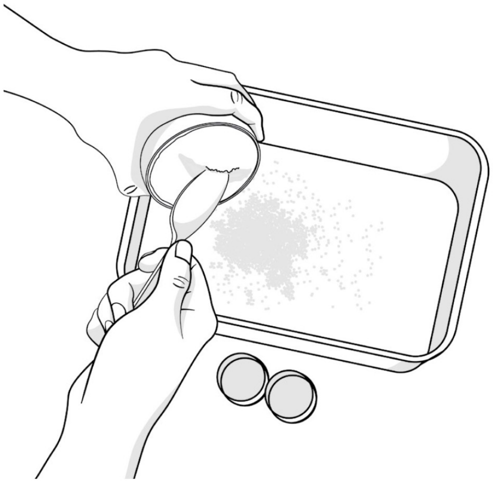


Figure 6 Get enough soil material to fill the WP4C cups half full

6. Turn the soil core around, and repeat step 4 for the next two cups.
7. Use a suitable cylinder, and press the soil column until half of the sample is out of the sampling ring. Cut the sample in half with a long, sharp knife (Figure 7). Take two more WP4C samples out of the middle following the procedure described in step 4.

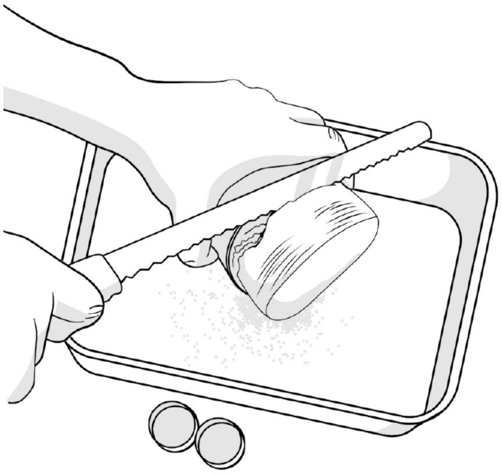


Figure 7 Cut the sample in half with a long sharp knife

NOTE: When storing the samples leave them at room temperature to avoid condensation.

TAKING WP4C READINGS AND POST PROCESSING

1. For option 1, it is necessary to leave the WP4C samples in closed cups for approximately 24 h equilibration time. For option 2, additional equilibration time is not necessary.
2. Carefully clean the HYPROP measuring head, and place all remaining soil together into one drying pan. Place the drying pan in the oven at 105 °C for 24 h to determine the dry soil weight.
3. Place the first of the six WP4C samples into the WP4C, and determine the water potential as described in the application note <u>WP4C Measurements Using LABROS SoilView Software</u>.
4. **Immediately** after finishing the WP4C measurement, remove the sample and place it on a precision scale (accuracy of ±0.001 g) to determine the gross weight (WP4C + cup) of the moist sample.
5. Repeat step 3 and step 4 for all remaining samples.
6. After measuring all six samples in the WP4C, dry them in the drying oven at 105 °C for 24 h.
7. After drying, remove the samples from the oven, let them cool down in a desiccator, and determine the gross weight (i.e., sample plus cups or drying pan) and tare weights (if not noted before).

CUTOFF POINTS FOR PRECISE AND CONTINUOUS MODES

The WP4C precise mode repeats water potential measurements on a sample until successive readings are 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.

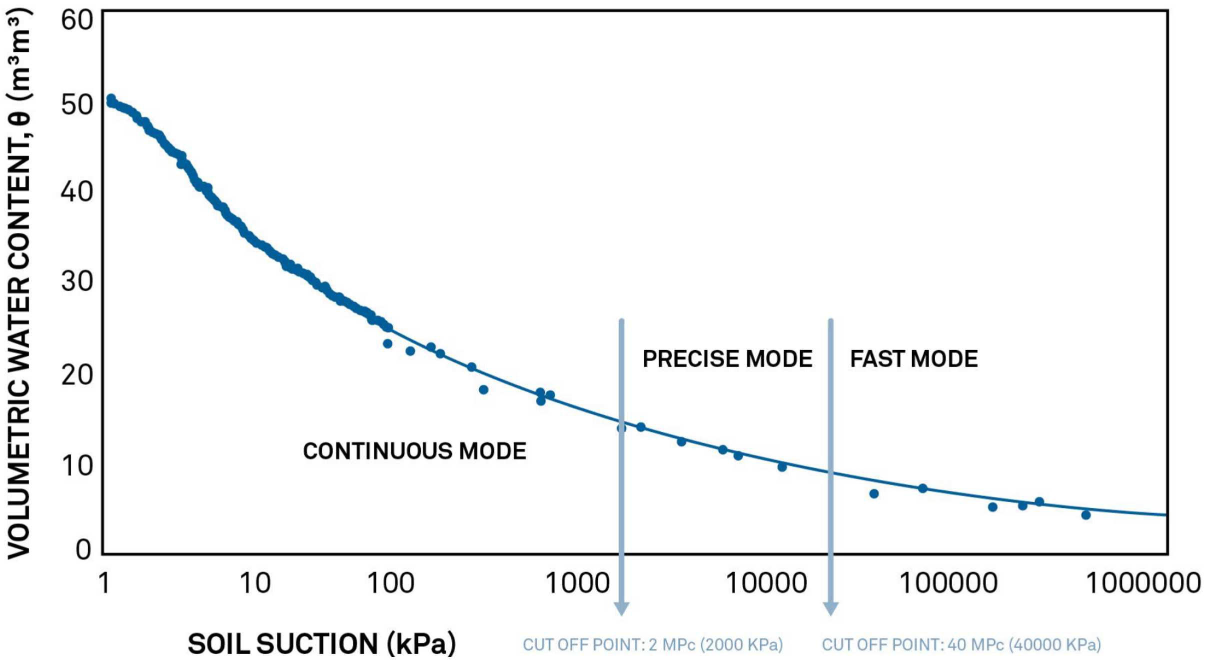


Figure 8 Cutoff points for WP4C precise and continuous modes

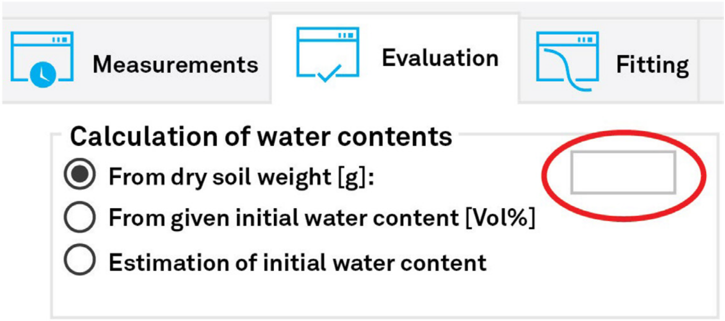
GETTING STABLE WP4C MEASUREMENTS INTO TENSIOMETER RANGE

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

For details on helpful experimental techniques, see Measuring Matric Water Potential With the WP4C.

DATA EVALUATION WITH LABROS SOILVIEW-ANALYSIS

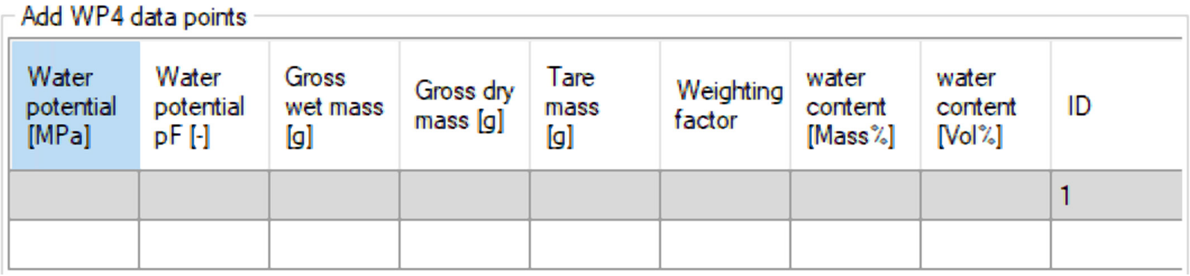
1. The weights for the dry soil core plus the six WP4C samples need to be combined and added to LABROS SoilView-Analysis. Insert total dry soil mass into the respective box of the LABROS SoilView-Analysis software (**Evaluation** tab, see Figure 9).



Calculation of water contents
● From dry soil weight [g]:
○ From given initial water content [Vol%]
○ Estimation of initial water content

Figure 9 Insert total cry soil mass into the repective box of the SoilView Analysis software

2. The WP4C data points will be added to the Excel table on the right side of the **Evaluation** tab. If WP4C data points have been added to an `*.bhdx` measurement file, they will automatically be displayed by opening the file. Otherwise the Excel file can be loaded by selecting the option **Add points from file** in the table. The weighting factor is `1` by default. The water contents will be calculated automatically considering the bulk density of the respective HYPROP sample.



Add WP4 data points

Water potential [MPa]	Water potential pF [-]	Gross wet mass [g]	Gross dry mass [g]	Tare mass [g]	Weighting factor	water content [Mass%]	water content [Vol%]	ID
								1

Figure 10 Insert the weights and MPa values

3. The resulting data will be illustrated in the retention data window of LABROS SoilView-Analysis and can be fitted with a suitable parametric model.

HOW TO MEASURE MATRIC WATER POTENTIAL 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 (approximately –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, see Protect From Temperature Gradients, it is possible to achieve precision to the 0.01 MPa level.

Table 1 **Equiliberation Time for Vapor Pressure Measurments With –0.20 MPa KCL Salt Solution**

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
23.3	–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

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 ±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 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 ±0.02 MPa between –2.2 MPa and 0. Table 2is an example data set. Note that all data were adjusted with the offset on the –2.238 MPa standard.

Table 2 Wet End Accuracy of WP4C Using Precision Solutions

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

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.

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, below is 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 min. 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 exit 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.

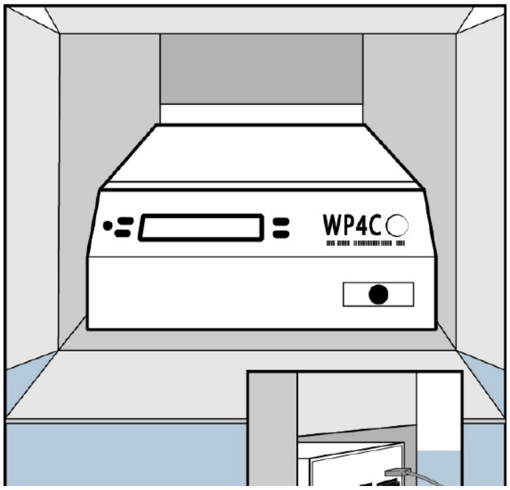


Figure 11 Place the WP4C in a cardboard box with a large vent hole at the rear of the WP4C

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 12.

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?

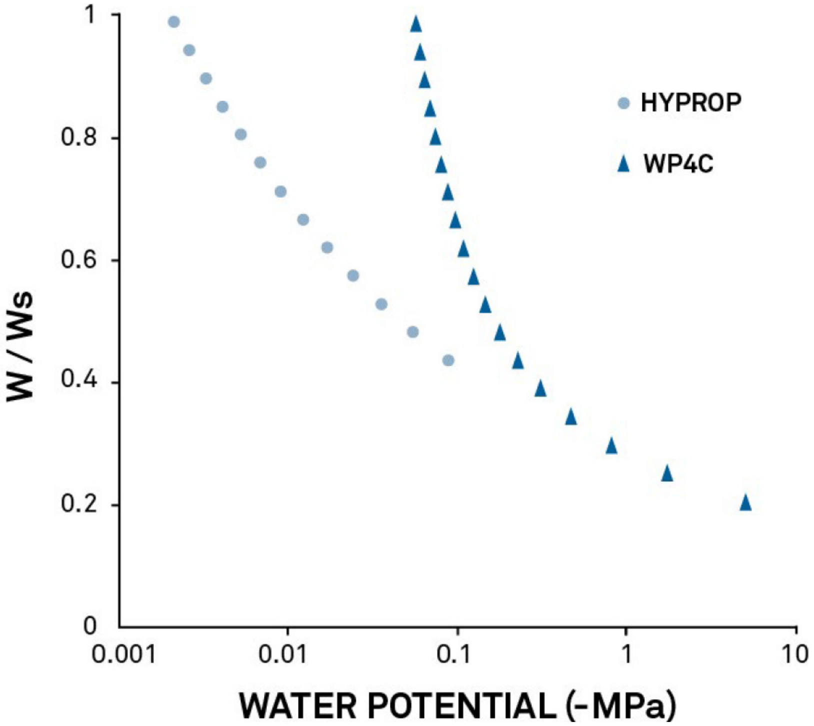


Figure 12 Moisture release curves generated by the HYPROP and WP4C of a silt loam with an EC of 1.4 dS/m

Vapor pressure methods, like the WP4C dew point potentiameter, 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 12.

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 7 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 6 with a smooth curve to meet the curve at around –3 MPa. To do something more quantitative, 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 the sample (USDA Handbook 60).

$$\psi_{OS} = -0.036\sigma_S$$

Equation 1

Where σ_s is the electrical conductivity of the saturation extract in dS/m. At other water contents the osmotic potential is

$$\psi_O = \psi_{OS}\frac{\omega_S}{\omega}$$

Equation 2

Here ω 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}. It is possible to get ψ_{OS} from electrical conductivity measurements, but it is easier to 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 ψ_{OS} and ψ_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.

$$\theta = \frac{\omega \times \rho_b}{\rho_\omega}$$

Equation 3

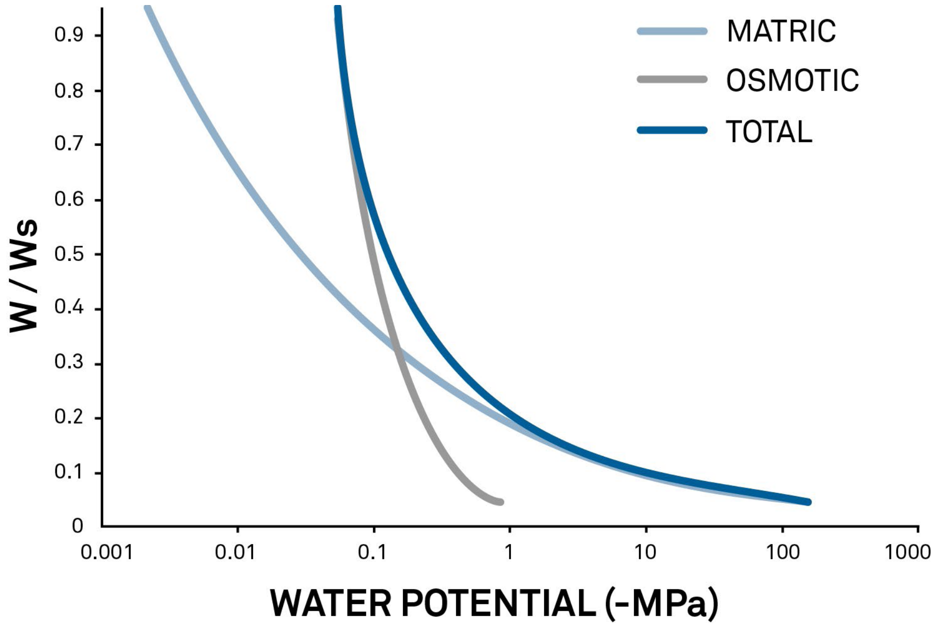


Figure 13 Complete picture of the matric, osmotic, and total matric potential of a silt loam soil

EFFECTS OF SAMPLE DISTURBANCE ON SOIL WATER POTENTIAL 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 equation, which relates the water potential of water beneath an air-water interface to the curvature of that interface.

Table 3 MPa comparison to pore diameter and pF

	kPa	pF	Pore Diameter (µm)
	-1	1.01	280.08
	-10	2.01	29.01
	-133	2.53	8.79
Field Capacity	-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	

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 15, from Box and Taylor (1962). They investigated the effects of bulk density on the moisture characteristic. Figure 15 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.

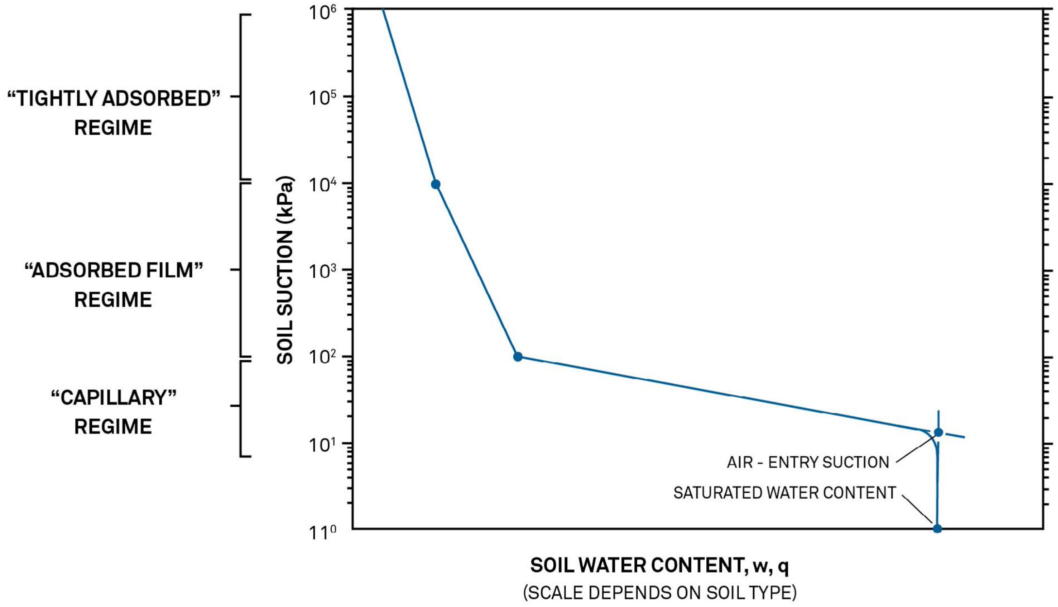


Figure 14 Idealized soil moisture characteristic from Lu and Likos (2004) showing the three soil moisture retention regimes

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 ±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 ±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 nonnegligible, and it is recommended to use minimally disturbed samples in the WP4C.

NOTE: The units of J/kg are equivalent to units of kPa.

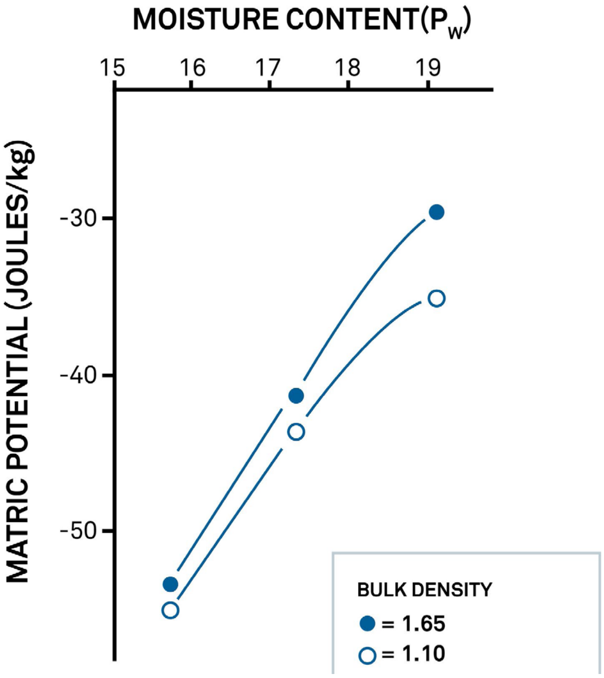


Figure 15 Box and Taylor (1962) graph showing changes in matric potential due to differences in bulk density

WANT TO UNDERSTAND MORE ABOUT RELEASE CURVES?

In this 20-minute webinar, learn how to use a moisture release curve to analyze individual soil behaviors with respect to water. Discover the following:

- The relationship between water content and water potential
- What a moisture release curve is
- What a curve can tell about the soil
- How to interpret moisture release curve data
- What to with the data

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. (Article link)

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. (Article link).

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

Durner, W. (2015): *Recommendation for an optimal combination of HYPROP and WP4 measurements to get a full range retention curve*. Braunschweig.

Hartge, H.; Horn, R. (1999): *Einführung in die Bodenphysik*. Stuttgart. (Article link)

METER Group, Inc. (n.d.): *Tools and Tips for measuring the full soil moisture release curve*. Pullman.