

Soil Water Retention Determination Using Pressure Plate Extractors

By Dane and Hopmans-SSSA; modified by David Huber

Table of Contents:

Introduction to soil water retention	2
Laboratory Analysis	3
Sample Collection	4-5
Sample Storage	5
Preparing the Wetting Solution	5
Soil Wetting	5
Pressure Plate Extractor:	6
General Principles	6
Equipment and Supplies	6
Procedure	6-8
Appendix	8

Introduction:

The relation between soil water (actually soil solution) content and matric potential is a fundamental part of the characterization of the hydraulic properties of a soil (Klute, 1986). This relation is referred to by various names, such as *water retention curve*, *water characteristic curve*. The function relates the water content or storage the energy state of the soil water. The energy state is expressed by names such as *suction*, *tension*, *soil water pressure head*, and *matric head*, h_m (m). For unsaturated soils, values for suction and tension are positive, while those for matric head are negative. We adopt the viewpoint that the soil water matric head is the result of pressure and adsorptive forces. Our measurement techniques, however, do not distinguish between pressure and adsorptive forces, and the methods as described in this chapter always yield h_m , whether adsorptive forces play a role or not. Matric head, h_m (m), is defined by

$$h_m = \Delta P / (\rho_w g)$$

where ΔP is the pressure difference across the gas–liquid interface in a unsaturated porous medium to the mean radius of curvature, ρ_w is the density of water (kg m^{-3}) and g is the gravitational field strength (N kg^{-1}).

The potential of soil water may be expressed in units of energy per unit mass (J kg^{-1}), energy per unit volume (N m^{-2} or Pa), or energy per unit weight (m). For most soil water applications, the use of energy per unit weight, referred to as *head*, is most convenient because it results in units of length. The matric head is thus expressed as the height of a fluid column of a given density. The fluid is usually water at the ambient temperature of the soil water system.

Soil water (solution) content may be expressed on a weight basis (gravimetric water content, kg kg^{-1}), a volume basis (volumetric water content, θ , $\text{m}^3 \text{m}^{-3}$), or a degree of saturation basis (volumetric water content divided by the porosity, σ). For the analysis of water flow in soil profiles, the use of volumetric water content is most convenient.

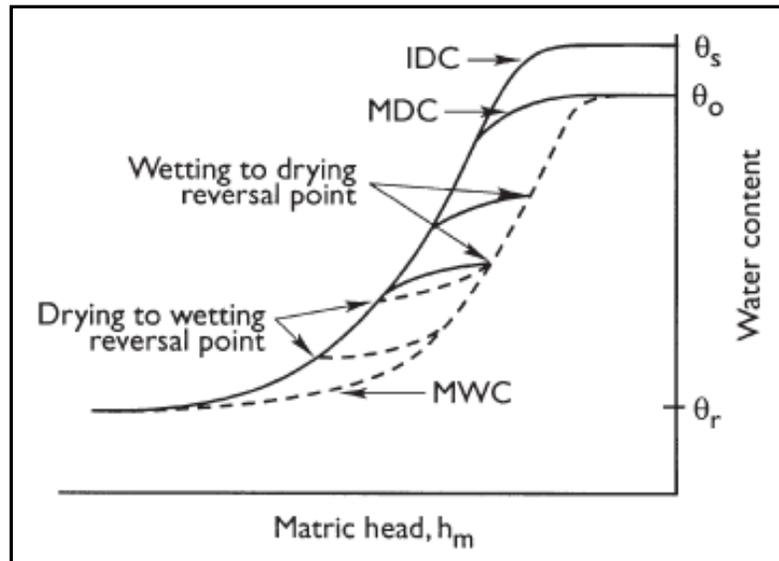
The need for knowledge of the water retention relation comes about for various reasons. In part, the soil water retention curve characterizes the soil type from which pore-size distribution and water holding capacity properties can be derived. In many other cases, the soil water retention relationship must be known to solve the Richards equation for unsaturated water flow.

The water retention curve is very much dependent upon the particle-size distribution, which determines the soil texture, and the arrangement of the solid particles, which is referred to as the *soil structure* (Salter & Williams, 1965; Richards & Weaver, 1944; Reeve et al., 1973; Sharma & Uehara, 1968; Croney & Coleman, 1954; Chapter 2). Organic matter content and the soil water composition also play a role in the shape of the water retention curve. Organic matter affects the shape of the retention curve directly because of its ability to adsorb water, and indirectly because of its effect on soil structure. Water retention curves of soils that contain swelling clay minerals are affected by the amount and composition of solutes present in the liquid phase (Dane & Klute, 1977).

Note: In concept, the methods presented here require that the retention data are obtained with the soil water at hydrostatic equilibrium; that is, at any time at which a data pair (h_m , θ) for the water retention curve is obtained, it is assumed that the soil water is at rest and the local soil water has adjusted to the changing curvature of the gas–liquid interface. However, one must be aware that hydrostatic equilibrium is *not always attainable*. An example of nonequilibrium behavior may be found in the application of the pressure plate extractor with applied gas pressures exceeding 100 kPa (1 bar). It is conceivable that the unsaturated hydraulic conductivity, $K(\theta)$, of certain soils may be so low that drainage rates become undetectable, hence making it difficult to ascertain hydrostatic equilibrium.

Laboratory Analysis:

General background: The traditional way of determining the water retention relation involves establishing a series of equilibria between water in the soil sample and a body of water at a known potential. The soil water system is in hydraulic contact with the body of water, usually via a water-wetted porous plate or membrane. At each equilibrium, the volumetric water content, θ , of the soil is determined and paired with a value of the matric head, h_m . Each data pair (θ , h_m) is a point on the retention function. Data points can be obtained during drainage of water from the sample (most common) or during imbibitions of water into the soil. Unfortunately, the two relations thus obtained will be



different; that is, the water retention relation is hysteretic and the water content during drainage will be greater than during wetting for a given value of the matric head as depicted in the figure above (Topp, 1969; Haines, 1930; Pavlakis & Barden, 1972). The drainage curve that starts at complete saturation of the porous medium is the initial drainage curve (IDC). As water is removed from a porous medium, the matric head decreases (i.e., it becomes more negative), and the water content approaches a limit called the residual water content, θ_r (often a curve fitting parameter used in modeling approaches). At this point the hydraulic conductivity of the soil has, for most practical purposes, become zero, and further drying of the sample can only be accomplished by evaporation. The main wetting curve (MWC) is obtained by wetting the soil from θ_r . As the soil is wetted along the MWC and the matric head approaches zero, the water content approaches a value, θ_0 , which is less than the porosity of the soil due to air entrapment. Usually θ_0 is about $0.85\theta_s$ (θ_s is the saturated water content; i.e., all pores are filled with water). The water content θ_0 is often referred to as the natural saturation or the field capacity. The drainage curve obtained beginning at θ_0 is called the main drainage curve (MDC). The existence of hysteresis complicates the modeling of soil water movement.

Soil samples: Soil samples for determining retention curves consist of either repacked, disturbed soil material or undisturbed samples. Before packing, the disturbed soil is often dried and passed through a 2-mm sieve. Since the structure of the soil affects the water retention, especially in the low suction range, it is *generally best to use samples of undisturbed nature*. Repacked samples are often used for more basic laboratory studies. Methods of procuring undisturbed samples were discussed by McIntyre (1974), and the most basic method is described in the next section.

The sample dimensions will generally be in the range of 5 to 8 cm in diameter and 1 to 6 cm in height. The time for reaching equilibrium is proportional to the square of the height of the sample. To minimize the equilibration time, the height should therefore be kept relatively small, but not so small that the samples cannot be handled properly. A practical height for many purposes is 2 to 3 cm, although the shorter the soil core, the less representative of the soil in situ soil structure. Therefore, the diameter and height of the sample should be relative to the size of the structural units (e.g., peds, cracks, worm and root holes, aggregates) over which the retention data are to be averaged.

Soil in situ is subjected to an external load due to the weight of overlying soil. In swelling soils, the external load on the sample affects the water retention curve (Collis-George & Bridge, 1973; Philip, 1969; Dane & Klute, 1977). When such soils are studied, consideration should be given to a method of applying, measuring, and controlling the external load on the soil sample although this is beyond the scope of this protocol.

Sample Collection:

The collection of intact soil cores should be viewed at the very least as a fine craft. If you show little regard for the integrity of the soil structure, your soil water retention functions will reflect this and may not represent field conditions. Determining the location of sample collection should be random but common sense is still needed when selecting the exact core location -- don't sample over a large soil crack or disturbed area (unless that is what you're trying to characterize). Grass covered soils are challenging to sample within the rooting zone and special care must be taken not to pull roots out when extracting the core from the surrounding soil.

Below is the procedure for sampling intact soil cores *by hand* from a relatively homogenous, rock free soil. Soils with a significant coarse fraction may require larger core diameters or alternate techniques to determine the soil moisture retention function.

1. Typically the upper centimeter or two of any soil consists of loosely consolidated mineral and organic material. In many arid systems, these organic layers can also be hydrophobic. Again, it depends on the goals of your study, but typically the upper 1-2 cm of soil should be gently removed using the edge of a spade (see adjacent picture).
2. Gently trim any vegetation protruding from the soil surface with scissors or clippers, making sure not to pull out any roots.
3. If the soils are dry, you may need to wet the soils prior to taking the core. If this is the case, pour water so it pools on and around the sampling location but do not pour directly where you will sample. It will take 10 to 30 minutes for the water to infiltrate deep enough to take a 5 cm soil core so you can prepare other sampling locations while you wait.
4. To depress the soil core into the soil, use a board placed across the top of the metal ring and apply weight uniformly. Be careful not to wobble back and forth while depressing the metal ring. Also, if at all possible, avoid any pounding action while inserting the metal ring -- often this causes cracking and disturbance of the soil core. If the metal ring stops, it probably hit dry soil -- apply more water and allow it to infiltrate once again. Sometimes however, use of a rubber mallet to pound the core in a short distance is unavoidable.
5. Dig out the soil to the side of the core making sure not to disturb the core or the soil beneath it. You will need to dig deep enough to allow the spade to insert parallel to the soil surface beneath the core (see adjacent picture).
6. Push the spade into the soil under the core until the bottom of the core is "capped" by the spade. Then gently pull the spade and core laterally out of the bulk soil.

Note: if there are lots of roots or the soil is too hard to stab into with the spade, you may need to "pop" the soil core out. This is done by using a trowel to leverage the core and the soil directly below the core out so you can then trim the roots and soil off more delicately (image this as an upside down muffin).

7. If the soil inside the core at the surface is intact keeping it from falling out, invert the soil core gently and trim off any extra soil and roots protruding from the base. A small metal cake spatula is ideal for this. The base of the core should be as flat and even with the base of the metal ring as possible.
8. If there are small pockets or holes in the soil on the bottom of the core, these must be filled in using finely powdered soil from approximately the same depth. Sprinkle the soil across the base of the core and then



use the metal spatula to evenly distribute and *lightly* pack the material. The base of the core is your contact surface for the soil moisture retention measurements so a flat continuous surface is important (see adjacent picture). You can add several drops of water to the base of the core to adhere the added soil material.

9. Tightly wrap the core in Saran wrap to prevent it from drying out or losing soil material. If the soil in the top of the ring is loose, you may need to fill the space between the soil surface and the top of the metal ring with cardboard or foam to prevent the core from falling apart.
10. Label core and place right side up in cooler.

Note: make sure to record the actual soil height and diameter either as you sample or prior to moisture retention measurements. This will allow you to convert all gravimetric measures of water content to volumetric values.



Sample Storage:

If undisturbed soil samples are to be stored for extended periods of time at their field water content, it is best to add a few drops of propylene oxide to each sample, cap them, and then store them in a refrigerator. This will prevent bacterial growth and the resulting formation of excretions (slime) that may affect the shape of the retention curve. It is important that the ends of the cores are trimmed flat prior to testing if not done in the field.

Wetting Solution:

The chemical composition of the wetting fluid can affect the water retention of the samples, particularly in fine-textured soils that contain significant amounts of swelling clays. In coarse-textured soils, little attention needs to be paid to the chemical make-up of the wetting liquid. Generally a fluid with a chemical composition similar to that of the indigent soil water should be used. However, this composition is usually unknown.

A deaerated 0.005 M CaSO₄ solution is suggested as a general test liquid. *Wetting with distilled or deionized water or freshly drawn tap water is not generally recommended.* The former promotes dispersion of the clays in the sample, and the latter is often supersaturated with dissolved air that may come out of solution after wetting the samples, causing the water content at a given pressure head to be affected. Due to the time duration over which a retention curve is determined, it is recommended that bacterial growth be inhibited by the addition of trace amounts of thymol to the wetting solution (Klute, 1986). These chemicals have a minimal effect on the surface tension of the soil solution when present in low concentrations.

Sample Wetting:

The method of wetting depends on whether points on the IDC or the MDC are to be determined (Recall general background discussion). For either determination, a thin mesh material must be placed over the base of the soil core to retain the soil when repeatedly measuring gravimetric water content with changing h_m . Typically a material like cheesecloth can be doubled up and tightly secured with a rubber band over the base. More ideal is the use of Nitex (6 Mesh), a thin nylon mesh that promotes better surface contact and retains less water itself. Nitex can be purchased from Soil Moisture Systems Inc. or through most online science supply vendors (e.g. BioQuip, Fisher Scientific, etc.). For a 5 cm diameter core, cut a 7.5x7.5 cm square and tightly and smoothly attach to the base of the core using a thick rubber band.

If points on the MDC are to be determined (as is typical), place the sample on top of a porous plate or membrane in the apparatus to be used to determine the water retention curve. Next, connect the outflow assembly to a source of wetting solution and let the water imbibe from the bottom of the soil sample. Slowly raise the external solution level to the near top of the sample ring. Once the wetting solution has wetted the surface of the soil, the sample can be assumed to be satiated. This process may take from several hours to many days, depending on the type of soil. It is important to remove all air from underneath the porous plate, as air may impede the wetting and/or drainage process.

Pressure Plate Extractor:

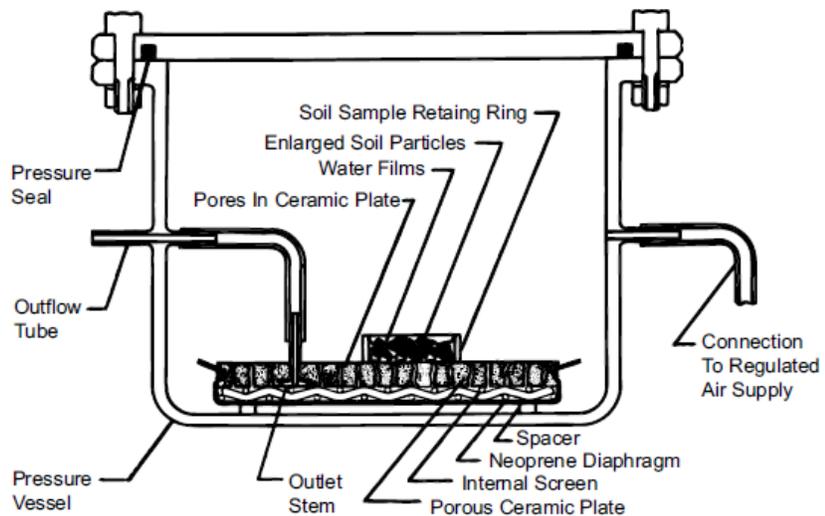
General Principles: Both the hanging water column and the pressure cell method are limited to a minimum h_m value of about -8.5 m. The use of a pressure plate extractor avoids this limitation because it is built to withstand high pressures. The principles are similar to those discussed for the pressure cell. Since we are now dealing with much higher pressures, and hence more negative values for h_m , we can assume that the change in h_m with elevation within the soil sample is negligible compared with the value of h_m itself. The values can therefore be calculated from

$$h_m = -(P_a - P_{atm}) / (\rho_w g) = -h_a$$

where again h_m is the matric head, ρ_w is the density of the wetting solution, and g is the gravitational force. P_a is the air pressure applied, P_{atm} is the atmospheric pressure outside the extractor, and h_a is the pneumatic component of the pressure head.

Equipment and Supplies:

Depending on the desired values of h_m , pressure plate extractors can be purchased that withstand pressures up to 500 (5 bar) or 1500 kPa (15 bar) (Soilmoisture Equipment Corp., P.O. Box 30025, Santa Barbara, CA 93105). Pressure plate extractors are substantially bigger than pressure cells. They can usually hold several porous plates. Each plate has a screen, to expedite lateral movement of water, and a rubber sheet covering the bottom. The rubber sheet is mounted to the edge of the plate (see adjacent figure). An outlet from the space between the plate and the backing sheet leads through the ceramic. This outlet is connected by a short piece of pressure tubing to an outlet in the pressure chamber. This outlet is in turn connected to a glass beaker or a burette slightly filled with water to detect air leaks. Water present between the plate and the rubber backing sheet is therefore near atmospheric pressure, independent of the air pressure applied to the soil samples present in the chamber. Each plate can hold from 5 to 12 soil samples. Plates are available with different bubbling pressures. Because the conductance of a plate decreases with increasing bubbling pressure, it is important to match the porous plate with the range of desired h_m values (e.g. 1/10 bar to 1 bar measures should be conducted on a plate rated up to 1 bar, measures between 1 to 5 bars on a plate rated to 5 bars, and so on).

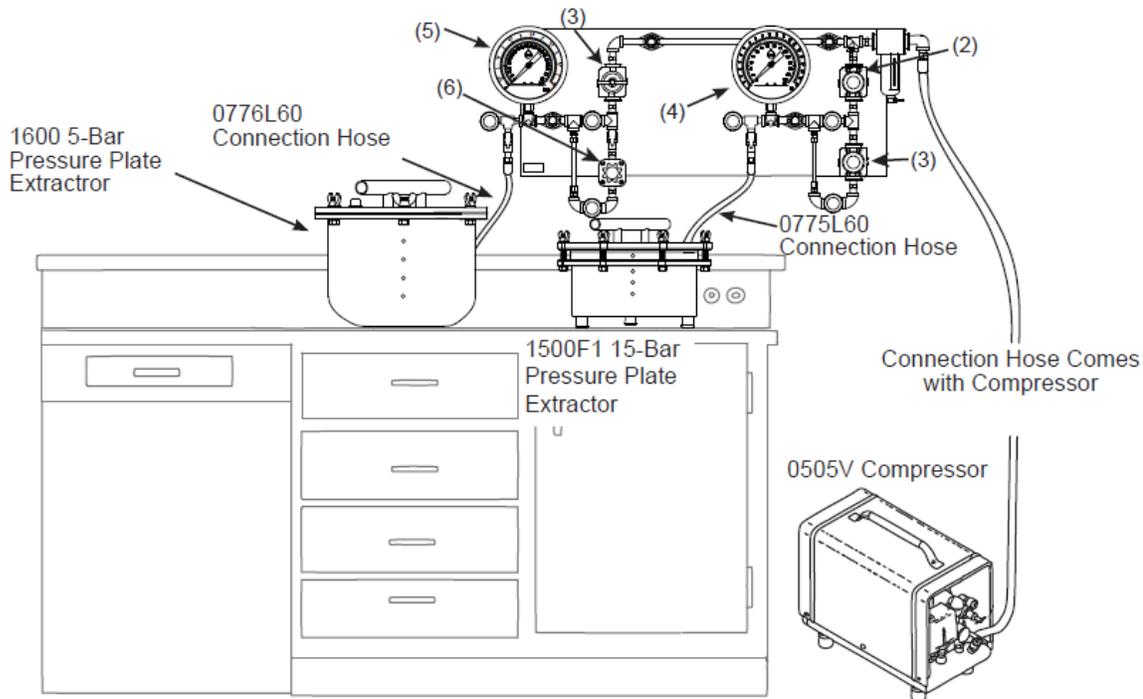


In addition to the pressure chamber(s) and porous plates, an air pressure supply and pressure regulation system is required (see below figure). An in-house air compressor, or bottled air or nitrogen, can be used as the pressure supply source. An air filter should be placed in the line between the compressed air (gas) and a nonbleeding type regulator to provide the specified pressure to a second regulator to be used in conjunction with the pressure chamber. Because of the relatively high pressures involved a pressure gauge should be used rather than a water and/or mercury manometer (all components are available from Soilmoisture Equipment Corp., Santa Barbara, CA 93105).

- (1) 0760G1 Air Filter
- (2) 0766P0250 Regulator, 10-250 psi
- (3) 0766P0150 Regulator, 5-150 psi, 2 each
- (4) 0780P0300, Test Gauge, 0-300 psi
- (5) 0780P0100, Test Gauge, 0-100 psi
- (6) 0765 Nullmatic Regulator, 1-60 psi

Lab 023 Setup is for the 1600 5-Bar Extractor and the 1500F1 15-Bar Extractor using the 0505V Compressor as a pressure source.

NOTE: If you wish to use a gas tank as a pressure source, refer to Lab 0523 Setup.



Procedure: The outlined procedure applies to both the 500- and the 1500-kPa pressure plate extractor apparatus, or to any similar pressure extraction system.

1. Make sure all pressure lines, filter, pressure regulators, and gauges are properly connected.
2. Take a porous plate with the desired bubbling pressure and saturate it with deaerated water (0.005 M CaSO₄ solution) by connecting the outlet to a water source and filling the space between the rubber backing sheet and the porous plate. At some point during the filling process, disconnect the supply tubing and remove the air from the space between the plate and the rubber sheet. Terminate the filling process once the rubber backing sheet is extended about 2 cm. Let the plate sit until considerable sweating of the ceramic plate is observed.

Note: not all labs are setup for this saturating process. A less ideal, but usually adequate, method is to place the plates in a bath of the deaerated water overnight to give the trapped air in the ceramic plate time to diffuse out.

3. Prior to placing plates in the pressure chamber, place several shallow tins full of water into the bottom of the chamber to help maintain the near 100% relative humidity in the headspace to minimize evaporative loss.
4. Drain most of the water from the space between the plate and the rubber sheet and place the plate in the pressure chamber. Connect the pressure tubing to the plate at one end and to the inside end of the pressure chamber outlet at the other end. Make sure that the tubing on the outside end of the pressure chamber outlet is connected to a burette or submerged under water in a glass beaker (this prevents the soils cores from drawing up water in the ceramic and subsequently drawing air into the backspace under the ceramic).

5. Place the saturated soil samples on top of the porous plate. The soil should be contained in rings.
6. Close the pressure chamber (make sure bolts are tight and properly seated) and apply the desired air pressure. Water will start to flow out of the pressure chamber, as can be observed from the water level in the burette or glass beaker. Excessive air bubbling from the outflow tubing is an indication of a leak in the porous plate. Measurements should be abandoned and restarted with another porous plate. Make sure the outflow tube is no longer submerged in the outflow solution.
7. Once outflow has ceased, disconnect the outflow tubing from the pressure chamber or clamp it closed to minimize backward water flow back into cores, reduce the applied pressure to atmospheric, open the pressure chamber, and quickly remove and weigh the moist samples (M_{ws}).
8. If water content values are needed at additional values for h_m , return the samples to the porous plate and repeat Steps 5 through 7. If no more measurements are needed, transfer the soil samples to tin cans and dry in the oven for approximately 48 h at 105°C to obtain the mass of the oven-dry samples (M_{ods}).
9. Calculate the volumetric water content corresponding to each value of h_m . If the volume of the soil is unknown, only the gravimetric water content (w) can be calculated according to

$$w = (M_{ws} - M_{ods})/M_{ods}$$

Appendix:

0 to 5 bar Moisture Retention Measures:

Description: The Model 1600 Pressure Plate Extractor allows analysis of the water-holding characteristics of soil samples in the 0 to 5 bar pressure range. The pressure vessel is 9" (22 cm) deep and has an inside diameter of 12" (30 cm). Up to 4 ceramic plates can be accommodated at one time, allowing approximately 48 each 2-1/4" (5.7 cm) diameter samples to be analyzed simultaneously depending on core height.



5 to 15 bar Moisture Retention Measures:

Description: The model 1500F1 – 15 bar (1500 kPa) Pressure Plate Extractor measures the moisture retention up to 15 bars (i.e. the theoretical wilting point for most plants). The chamber is designed to hold up to 24 – 1.2" (3 cm) height core samples or 12 – 2.4" (6 cm) height cores. Choose plate cells for measurements between 5 to 15 bars to suit your needs. You'll need to have a pressure manifold available (see below), and you'll also need a compressor or compressed air tank as well rated for 15 bar pressure loads.

