

STANDARD OPERATING PROCEDURE

Determination of Soil Water Characteristic Curve Using 5 Bar Ceramic Pressure Plate Extractor

KEY WORDS

Soil water characteristic curves, pore-size distribution, pressure plate extractor, soil water content, matric potential, undisturbed soil samples

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1.0 INTRODUCTION

1.1 Purpose

Soil water characteristic curve, also referred to as retention curve, describes the relationship between soil water content and soil water suction and is a fundamental part of the characterization of soil hydraulic properties. It depends on soil texture and soil structure (Klute, et al., 1986). Soil water characteristic is a basic soil property that is required for the study of plant-available water, infiltration, drainage, hydraulic conductivity, irrigation, water stress on the plants, and solute movement in subsurface soil (Kern, 1995). One method to determine soil water characteristic curves in the laboratory is by using a pressure plate extractor, applying various soil suctions, and measuring the changes in soil water content. This standard operating procedure (SOP) outlines how to determine soil moisture content at various pressures (between 0 to 5 bar) to create the soil water characteristic curve.

1.2 Definitions

Deionized (DI) Water is water that has had the ions removed. Deionization does not significantly remove uncharged organic molecules, viruses, or bacteria except by incidental trapping.

Field capacity is the amount of water that a well-drained soil would hold against gravitational forces or the amount of water remaining when downward drainage has markedly decreased (Taylor and Ashcroft, 1972).

Undisturbed soil sample is a soil sample that has not undergone any physical processing since collection and its natural structure is preserved.

2.0 APPLICATION

The 5 Bar Ceramic Pressure Plate Extractor provides a sturdy, positive sealing pressure vessel that accepts the various ceramic pressure plates available in the range of 0 to 5 bar soil water suction (Soil Moisture Equipment Corp., 2008). Soil suction at field capacity will vary with soil texture and structure. The soil water content at applied pressures of 0.10 and 0.33 bar can correspond to field capacity. If the soil texture is coarse (e.g., sand, loamy sand, or sandy loam), the soil water content at 0.10 bar pressure can be considered at field capacity. For all other finer soil types, the soil water content at 0.33 bar applied pressure can be assumed to be at field capacity. Undisturbed soil samples subjected to pressures higher than 1 bar will require additional time to attain soil water content

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equilibrium. Although this SOP recommends applying three pressure steps (0.10, 0.33, and 0.90 bar), users can add more intermediate pressure steps in order to generate a more detailed soil water characteristic curve.

3.0 MATERIALS

- 3.1 Saturated undisturbed soil sample(s)
- 3.2 5 Bar Ceramic Pressure Plate Extractor (Soil Moisture Equipment Corp., 2008)
- 3.3 (2) 1 or 3 bar ceramic plates
- 3.4 (2) Compressed nitrogen gas (N₂) (300 ft³ gas volume or 49 L water capacity)
- 3.5 Wash bottles filled with deionized (DI) water
- 3.6 Outflow tubes
- 3.7 Regulator, gauges
- 3.8 Handheld read-out device (INFIELD7C) with pressure transducer
- 3.9 Analytical balance (accurate to 0.01 g)
- 3.10 Masking tape
- 3.11 Parafilm
- 3.12 (1) 500 mL beaker
- 3.13 (2) 125-250 mL flasks
- 3.14 Plastic storage bin with lid
- 3.15 Lab spatula
- 3.16 Kimwipes
- 3.17 Aluminum cans (250 mL)
- 3.18 Sharpie permanent marker (Black)
- 3.19 Drying oven
- 3.20 Oven mitts
- 3.21 6x9-inch sealable nylon bags
- 3.22 Desiccator

4.0 PROCEDURES

4.1 Soil Preparation

- 4.1.1 Prepare undisturbed soil samples confined within stainless steel rings (Figure 1) according to the procedures described by Fong et al. (2018).

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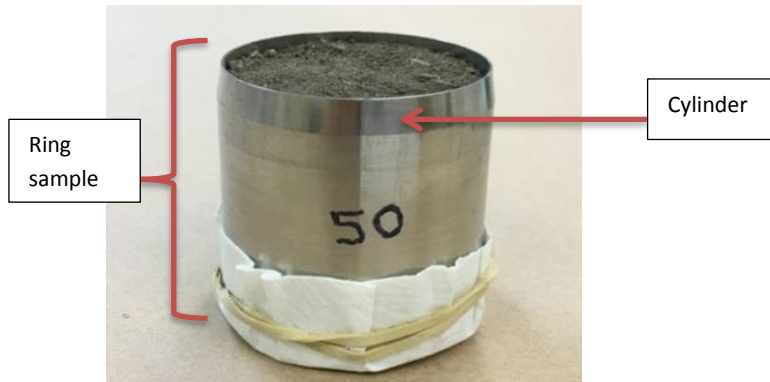


Figure 1. Prepared ring soil sample ready to be used in the pressure vessel.

4.2 Preparing the ceramic plates

4.2.1 Place two clean, dry ceramic plates into the empty plastic storage bin. The 1-bar ceramic plate is required for the 0 to 1 bar range of soil suction, whereas the 3-bar ceramic plate is required for soil suction in the 0 to 3 bar range. For pressure applications higher than 1 bar, soil water flows mostly through the smaller pore sizes at a very slow rate. Users need to be aware of the long equilibration times for drainage of soil water at pressures above 1 bar. The equilibration times depend on soil types and ranges between one to two weeks.

4.2.2 Add enough DI water to the plastic storage bin to completely submerge the two ceramic plates and then cover the bin with its lid. Keep the ceramic plates submerged for 24 hours to allow them to reach complete saturation (Figure 2).



Figure 2. Two ceramic plates submerged in DI water for 24 hours.

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4.3 Setting up the ceramic plate extractor

- 4.3.1 Remove and set the extractor lid on its handle bar so that the underside of the sealing area is not damaged (Figure 3).

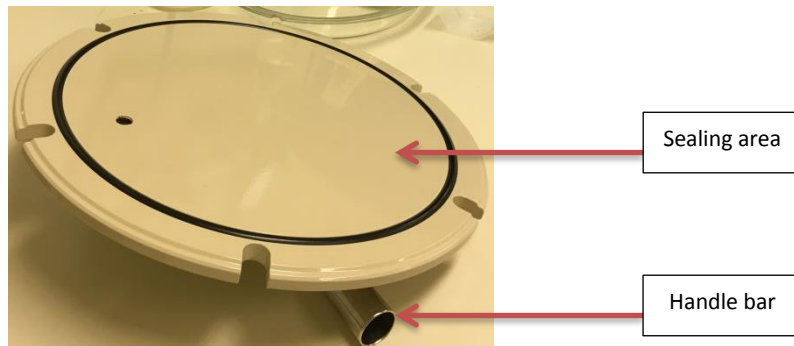


Figure 3. Extractor lid properly set on its handle bar.

- 4.3.2 Place the first ceramic plate on the stainless steel support clips at the bottom of the pressure chamber (Figure 4).

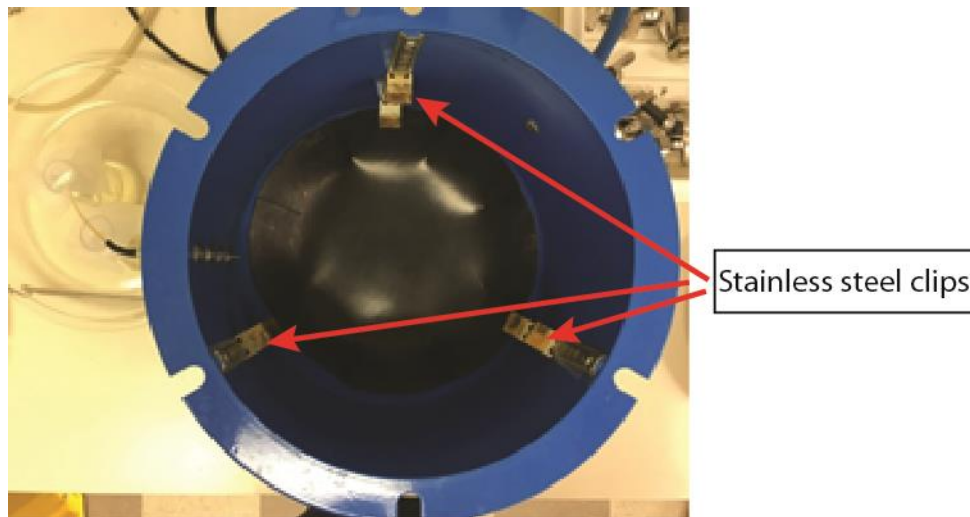


Figure 4. Stainless steel clips placed to support the ceramic plates.

- 4.3.3 Ensure that the neoprene diaphragm attached to the rim of the pressure plate is positioned so that its edges are above the upper surface of the pressure plate. Confirm that there are no folds in the positioned neoprene diaphragm (Figure 5).

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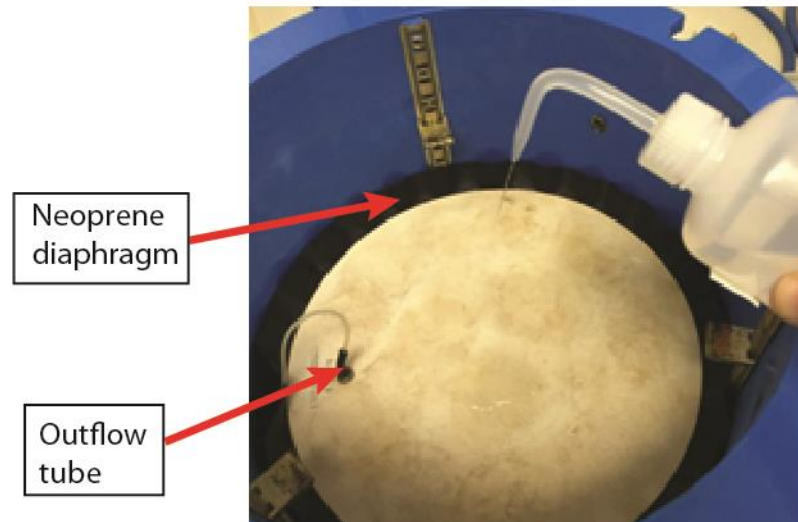


Figure 5. Spraying DI water onto the ceramic plate.

- 4.3.4 Connect the outflow tube on the ceramic plate to the lower outflow port on the side of the extractor (Figure 5). If necessary, rotate the plate so that the outflow tube is close to the outflow port. Spray DI water onto the ceramic plate so that the standing water level should be around 0.5 mm in height to help create initial hydraulic contact between the soil ring samples and the ceramic plate (Figure 5).
- 4.3.5 Place the soil samples on the ceramic plate with the beveled edge of the sample rings facing up. The first ring sample is placed next to the outflow tube. The other ring samples are placed close to each other at a distance of about 0.5 cm between the soil ring samples and the neoprene diaphragm. Each plate can accommodate approximately 15 ring samples (Figure 6).
- 4.3.6 Spray additional DI water onto the ceramic plate between the ring samples to ensure hydraulic continuity between the ceramic plate and the ring samples (Figure 6). The standing water level should be around 1 mm in height. Avoid spraying water onto the ring samples.

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Figure 6. Additional DI water applied to the ceramic plate in between the ring samples to ensure hydraulic continuity.

- 4.3.7 Repeat steps 4.3.2 through 4.3.6 for the next ceramic plate, which should be placed on the second level of stainless steel clips (Figure 7A and B).



Figure 7. (A) Second ceramic plate connected to the outlet port; (B) Setup of ring samples on the second ceramic plate.

- 4.3.8 Close the extractor lid and align it to the pressure vessel. Attach one wingnut at a time.
- 4.3.9 Ensure the washers of the wingnuts are on top of the extractor lid (Figure 8A).

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- 4.3.10 The rectangular head of the wingnuts should fit properly into the constraining groove on the bottom side of the lower clamping ring (Figure 8B).

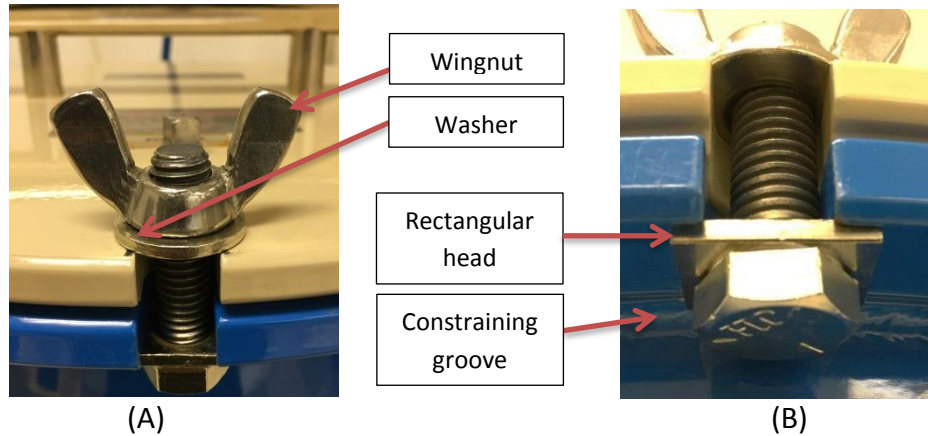


Figure 8. Alignment of wingnut to secure the lid to the pressure vessel.

- 4.3.11 Push upward on the wingnut from the bottom when tightening to set it in place.
- 4.3.12 After the wingnuts are in place, simultaneously tighten two opposing wingnuts in sequence until all six wingnuts are secure. Check that all the wingnuts are securely tightened.

4.4 Setting up the nitrogen gas as a pressure source

- 4.4.1 Obtain two full compressed nitrogen tanks (300 ft³ gas volume or 49 L water capacity). One tank is connected to the pressure vessel; the other is a spare. The nitrogen tank can be used until the pressure gauge drops to 300 psi, at which point the nitrogen tank should be replaced. See section 4.7 for changing the nitrogen tank during the experiment.
- 4.4.2 For the release and isolation valves, a vertical (0°) position indicates open and a horizontal (90°) position indicates closed (Figure 9). For all other valves and regulators, turn counterclockwise to open and/or release pressure and turn clockwise to close and/or load pressure. Observe that the pressure gauge should show “0” pressure. If the pressure gauge shows some pressure, release the pressure with the coarse and fine valves by turning counterclockwise (Figure 9). The isolation valve should remain open (Figure 9). Ensure that the exhaust valve is

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closed. Close the release valve to avoid accidental pressure load to the pressure plate extractor.

- 4.4.3 Check that the coarse and fine regulators are initially fully open (Figure 9).
- 4.4.4 Open the main valve on the nitrogen gas tank connected to the apparatus (Figure 10).
- 4.4.5 Close the exhaust and release valves (Figure 9).
- 4.4.6 Turn the coarse regulator clockwise several times to load the pressure onto line and then turn the fine regulator clockwise to set the approximate desired pressure. To prevent a nitrogen leak, minimize the pressure difference between the coarse and fine regulators. Observe the pressure gauge and adjust the fine regulator to the target pressure of 0.10 bar (= 100 hPa). Ensure that the upper valve is closed and the lower valve is open.

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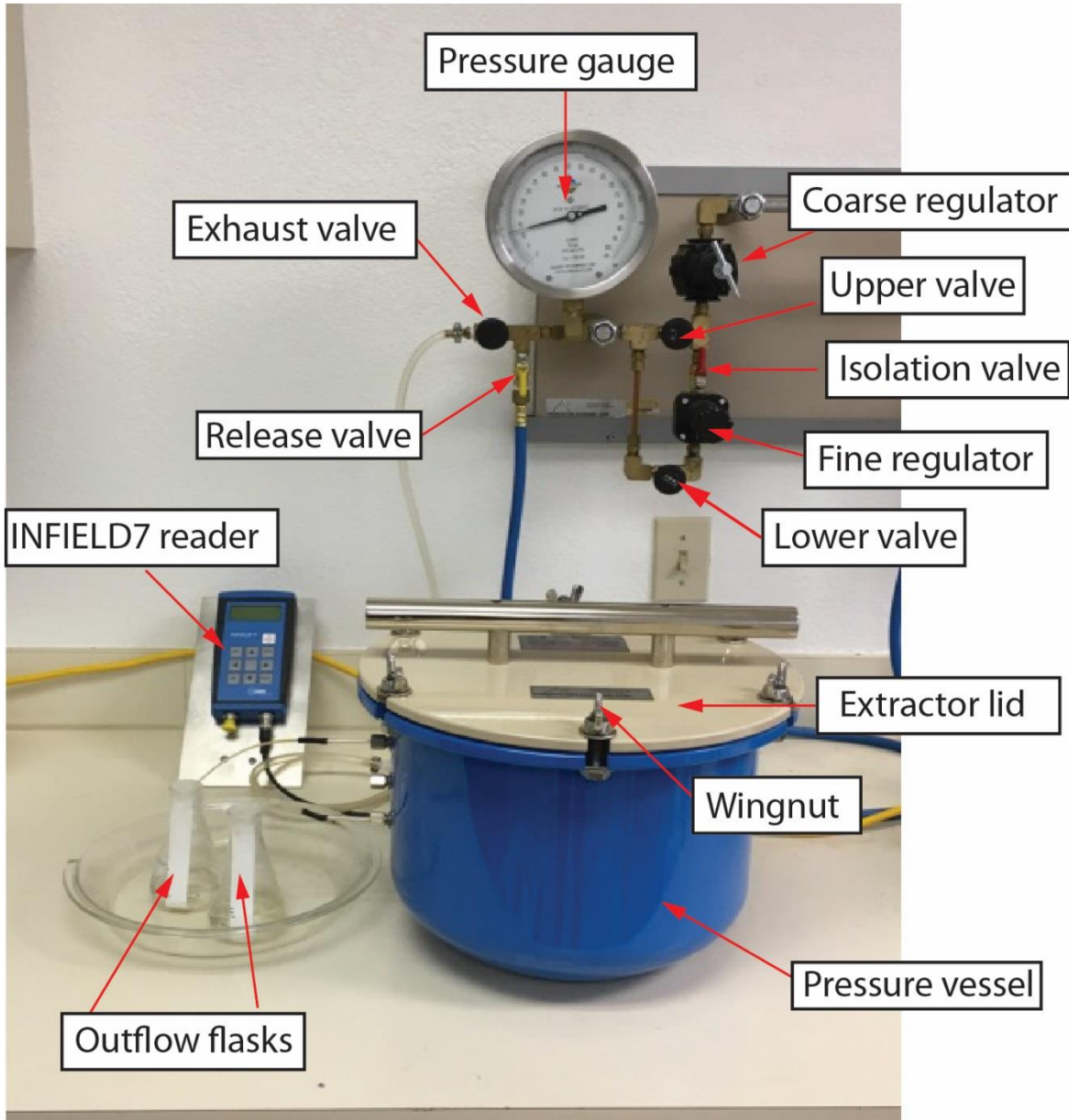


Figure 9. Laboratory setup for the pressure vessel using a regulated air system and INFIELD7 Reader.

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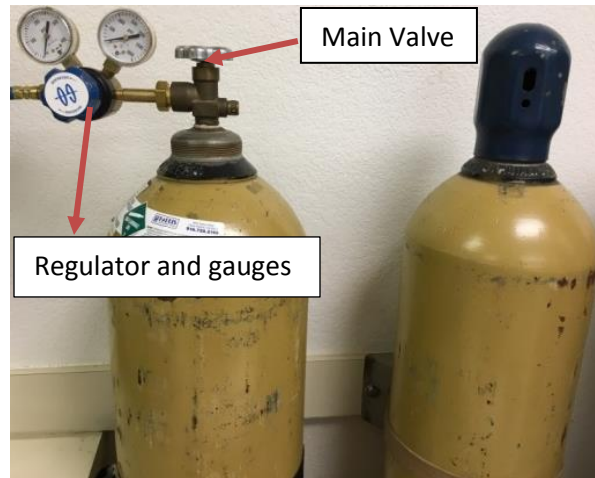
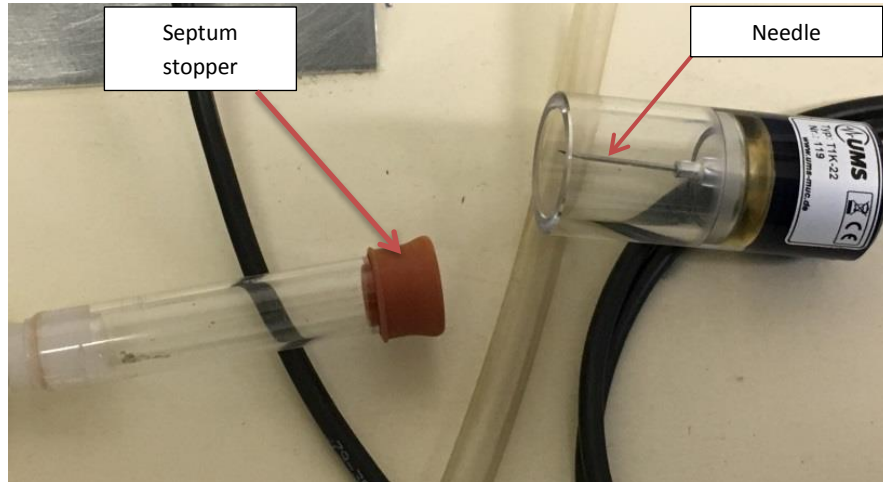


Figure 10. Nitrogen tank in use (left) and backup nitrogen tank (right).

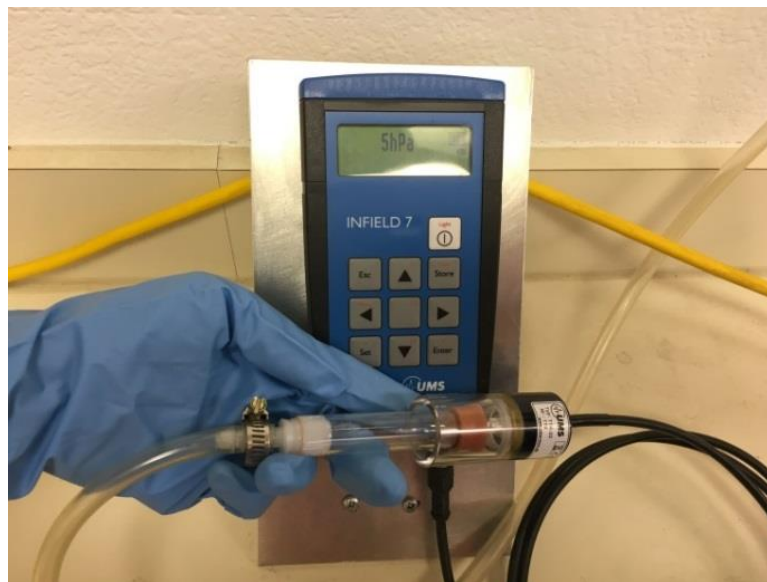
- 4.4.7 To measure the applied pressure precisely, open the exhaust valve. Insert the needle attached to the INFIELD7 hand-held pressure reader (INFIELD7C, 2009) into the septum stopper connected to the exhaust valve via tygon tubing (Figure 11A). The hand-held reader more precisely measures pressure than the mechanical pressure gauge does. This is especially relevant when controlling for low pressures where water extraction from the soil samples is particularly sensitive to pressure (Figure 9 and 11B).
- 4.4.8 Turn on the INFIELD7 reader by pressing the power button (Figure 11B). The applied pressure will display in hPa.
- 4.4.9 Once the target pressure of 0.10 bar (100 hPa) is set by adjusting the fine regulator, turn off the INFIELD7 reader by pressing and holding the power button. The operational range of INFIELD7 reader is between 0 and 1 bar.
- 4.4.10 Close the exhaust valve by turning it clockwise (Figure 9).
- 4.4.11 Slowly open the release valve to release pressure into the pressure plate extractor. Remember that the vertical (0°) position means the valve is open; a horizontal (90°) position means the valve is closed (Figure 9).

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(A)



(B)

Figure 11. (A) Needle (right) to be inserted into the septum stopper (left) to measure pressure more precisely; (B) INFIELD7 Reader turned on and showing the pressure in hPa.

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4.4.12 Place the outflow tubes into a 500 mL beaker to capture the excess water (Figure 12).

4.4.13 Once the excess water flow rate decreases, transfer the tubes into two 125 mL flasks, to which tape has been applied to the side for marking the water levels (Figure 13). Cover the openings of the flasks with parafilm.

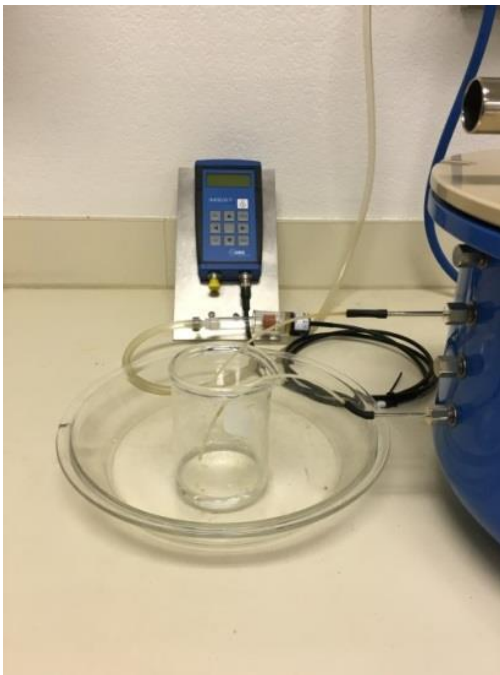


Figure 12. 500 mL beaker to capture excess water.



Figure 13. Two 125 mL beakers (with tape applied) used to capture and measure water.

4.4.14 Mark the water heights twice per day on the applied tape, once at the beginning and then at end of the day (Figure 13). Once the water flow into the tubes ceases for approximately 24 hours, the soil samples inside the pressure vessel have reached the equilibrium water content at the applied pressure.

4.5 Removing the samples from the pressure plate extractor

4.5.1 Turn the fine regulator valve counterclockwise and release the pressure in the pressure plate extractor. Do not adjust the coarse valve.

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- 4.5.2 Wait until the sound of escaping gas has stopped and the pressure gauge has reached "0".
- 4.5.3 Loosen and remove all the wingnuts from the extractor lid.
- 4.5.4 Remove and set the extractor lid on its handle bar so that the underside of the sealing area is not damaged (Figure 3).
- 4.5.5 Pick up and remove the ring samples from the pressure vessel by slightly twisting them to break their contact from the top ceramic plate. Place the ring samples into a new storage bin. Cover the storage bins and pressure plate extractors with their lids to prevent any evaporation from the soil ring samples and ceramic plates. To ensure the integrity of the samples and to maintain their soil water content, weigh the soil sample rings soon after removal from the pressure vessel.
- 4.5.6 Record the total weight of the ring-confined soil sample including the rubber band and filter paper in Table 1 (Figure 14).



Figure 14. Weighing of the whole ring sample.



Figure 15. Weighing of the rubber band.

- 4.5.7 Record the weight of the rubber band (Figure 15) in Table 1.
- 4.5.8 Lay the ring sample on its side in a plastic weigh boat (Figure 16A) and carefully remove the filter paper (Figure 16B).

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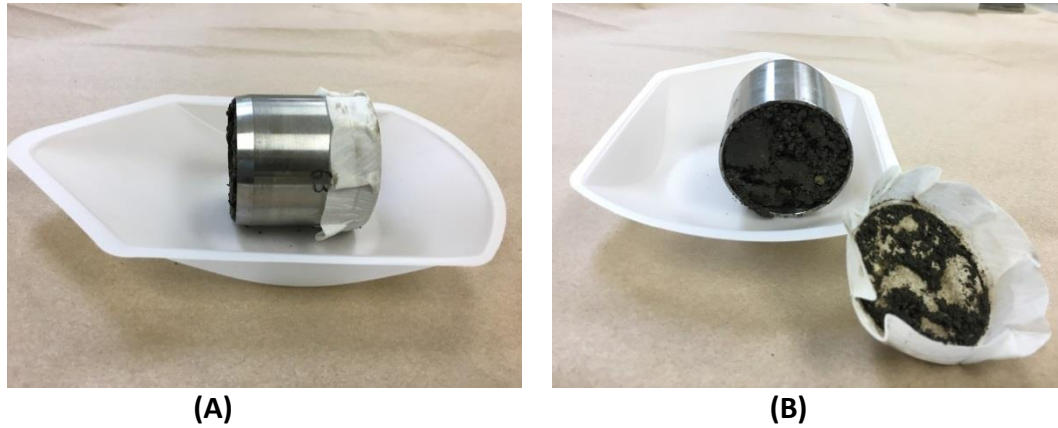


Figure 16. (A) The ring sample with filter paper; (B) removal of the filter paper from the ring sample.

4.5.9 Use a spatula to scrape the soil affixed to the filter paper; use this soil to replace the missing soil in the ring that was removed from the filter paper (Figure 17).



Figure 17. Cleaning soil residue from filter paper.

4.5.10 Clean the outside of the cylinder with a Kimwipe if there are residues of soil.

4.5.11 Record the weight of the soil-free filter paper in Table 1 (Figure 18). Discard the filter paper after weighing.

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Figure 18. Weighing of the soil-free filter paper.

- 4.5.12 Brush soil from the work station and wipe the spatula with a Kimwipe.
- 4.5.13 After weighing, place the ring samples back into the same storage bin. Cover the storage bin to prevent evaporation from the samples while the soil ring samples on the bottom ceramic plate are removed.
- 4.5.14 To access the second batch of soil ring samples, unplug the outflow tube on the top empty ceramic plate. With both hands, lift the top ceramic plate from the neoprene diaphragm without disturbing the ring samples on the bottom ceramic plate.
- 4.5.15 Repeat steps 4.5.4 and 4.5.5 to transfer the ring samples on the bottom ceramic plate into the storage bin where the first batch of soil ring samples are temporarily stored.
- 4.5.16 Apply DI water to the bottom ceramic plate with a squirt bottle to create hydraulic continuity between the plate and the soil ring samples. Place the previously weighed first batch of soil ring samples in the storage bin onto the bottom ceramic plate as directed in step 4.3.5. Apply additional DI water onto the ceramic plate between the ring samples as directed in step 4.3.6. Avoid spraying water onto the ring samples (Figure 6). These soil ring samples are ready for the second pressure

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application.

4.5.17 Repeat steps 4.6.2 to 4.6.9 for the soil ring samples removed from the bottom ceramic plate.

4.5.18 Place the top ceramic plate back into the pressure vessel as directed in step 4.3.7. Apply more DI water onto the ceramic plate to create hydraulic conductivity between the plate and the soil ring samples. Place the soil ring samples back onto the top ceramic plate as directed in step 4.3.5. Apply additional DI water onto the ceramic plate between the ring samples as directed in step 4.3.6. Avoid spraying water onto the ring samples (Figure 6).

4.5.19 Repeat steps 4.3.8 through 4.3.12 to close the lid of pressure vessel.

4.6 Preparing for increased pressure applications

4.6.1 Repeat steps 4.4.2 to 4.4.14 for the second pressure application of 0.33 bar (330 hPa).

4.6.2 After drainage from the outflow tube has decreased, repeat steps 4.5.1 to 4.5.4 to remove the samples at the end of 0.33 bar soil water equilibrium procedure. Repeat steps 4.5.1 to 4.5.11 to determine the soil moisture content at 0.33 bar.

4.6.3 Repeat steps 4.4.2 to 4.4.14 for the third pressure application of 0.90 bar (900 hPa).

4.6.4 Repeat steps 4.5.1 to 4.5.11 to determine the soil moisture content at the 0.90 bar pressure step. If the user desires additional soil moisture-content data beyond the three tested pressures, then steps 4.3.7 to 4.5.15 can be repeated using other intermediate pressures.

4.7 Changing the nitrogen tank during the experiment

As mentioned in section 4.4.1, the nitrogen tank can be used until the pressure gauge drops to 300 psi. During the measurement, if the pressure level drops below 300 psi, replace the tank with the spare full tank. To replace the tank, take the following steps:

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- 4.7.1 To remove the empty tank:
 - 4.7.1.1 Turn the release valve into a horizontal (90°) position to close (Figure 9). This is an important step to keep pressure level at the same level in the pressure vessel.
 - 4.7.1.2 Close the main valve on the nitrogen gas tank (Figure 10). Please do not touch the coarse or fine regulators of the system.
 - 4.7.1.3 Remove the regulator connected to the empty nitrogen gas tank using a steel wrench.
 - 4.7.1.4 Place its cap on the empty nitrogen gas tank to protect the main valve.
- 4.7.2 To install the full tank:
 - 4.7.2.1 Remove the cap of the spare nitrogen gas tank and connect the regulator to the tank using the steel wrench.
 - 4.7.2.2 After ensuring all connections are secured, open the main valve on the tank and then open the release valve on the system (Figures 9 and 11). A full tank generally starts between 2300 and 2400 psi. Loading pressure back onto system might change the pressure level in the pressure vessel. If the pressure gauge or the INFIED7 hand-held pressure reader show a change in the pressure level (Figures 9 and 12), adjust the pressure level with fine regulator accordingly (Figure 9).

5.0 CLEANING THE CERAMIC PLATE EXTRACTOR

- 5.1 After conducting the final pressure setting, remove the outflow tube from the outflow port of the pressure vessel. With both hands, lift the top and bottom ceramic plates by the neoprene diaphragm. Avoid using soap when scrubbing and rinsing the ceramic plates with DI water. Do not press fingers on the ceramic part of the plate to prevent plugging the ceramic plate pores with soil and oil. Let the ceramic plate air-dry in a secure place before storing it.
- 5.2 Wipe the pressure plate extractor with a paper towel and air-dry the inside of the extractor to prevent the steel clips and inner walls from rusting. After drying, close the extractor with its lid secured lightly by a single wingnut. Ensure that the main valve on the nitrogen tank is closed (Figure 10).

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6.0 DETERMINING SOIL MOISTURE CONTENT

6.1 After weighing the soil ring samples at the last applied pressure, place them horizontally into aluminum cans. Record the soil sample numbers on the outer wall of each can at two places with a felt pen (Figure 19).



Figure 19. The soil ring sample in an aluminum can is ready to go in the drying oven.

6.2 Transfer the soil ring samples to a drying oven (Figure 20). Set the temperature of the oven to 105 °C. To turn on the oven, press and hold the power button (Figure 21).



Figure 20. Samples in the drying oven.



Figure 21. Drying oven turned on.

6.3 Allow the ring samples in the aluminum cans to dry in the oven for 24 hours.

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- 6.4 After 24 hours, use oven mitts to transfer the ring samples in the aluminum cans from the oven into a desiccator with an active desiccant for cooling (Figure 22).
- 6.5 The desiccator can hold 12 samples at a time (Figure 22B). To open the desiccator, slide the lid off. The samples can be stacked into three levels. To create another level of samples, stack the first sample of the new level as shown in Figure 22A. The first level has four samples, the second level has four samples, and the third level has three samples (Figure 22B). Slide the lid on to close the desiccator(s).



(A)



(B)

Figure 22. (A) Stacking the first level of soil ring samples in the desiccator; (B) Finalized stacking of all three levels of soil ring samples.

- 6.6 Keep soil sample rings waiting to be treated by the desiccator in the hot oven to prevent the soil samples from absorbing additional air moisture.
- 6.7 Allow the samples to cool for 40 min in the desiccant.
- 6.8 Record the weight of the cooled soil samples in the aluminum can in Table 2.

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6.9 Label a 6x9-inch sealable nylon bag with the soil sample information (number, date sampled, location, etc.). Remove the soils from the stainless steel ring and transfer them into individual nylon bags and store for future soil analyses.

6.10 Wash the stainless steel rings and aluminum cans with soap and water.

6.11 Completely dry the stainless steel rings and aluminum cans with paper towels or by placing them in the oven.

6.12 Record the weight of the stainless steel ring and aluminum can in Table 2.

6.13 Calculating soil moisture content

6.13.1 Calculate soil moisture content of the samples on a volume basis (volumetric water content) ($\text{cm}^3 \text{ cm}^{-3}$) at each applied pressure using the following formula:

$$\theta = \frac{(\text{Weight of wet soil at each applied pressure (g)} - \text{Weight of oven dry soil (g)}) / \rho_w (\text{g cm}^{-3})}{\text{Volume of soil ring (cm}^3)}$$

where ρ_w is density of water at laboratory conditions ($\sim 1 \text{ g cm}^{-3}$)

6.13.2 Calculate oven-dry bulk density, ρ_b (g cm^{-3}),

$$\rho_b = \frac{\text{Weight of oven dry soil (g)}}{\text{Volume of soil ring (cm}^3)}$$

6.13.3 Calculate porosity, ϕ ($\text{cm}^3 \text{ cm}^{-3}$),

$$\phi = \frac{(\rho_s - \rho_b)}{\rho_s} = 1 - \frac{\rho_b}{\rho_s}$$

where ρ_s is particle density and approximately equals to 2.65 g cm^{-3} . The user can also determine particle density specifically for the designated soil sample by following the procedure Tuli (2015) describes.

Data and calculations from "Table 2: Datasheet for calculations" can also be recorded in the Excel spreadsheet "Soil Retention Calculations."

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7.0 TROUBLESHOOTING

- 7.1 For any problems with the pressure plate extractor, refer to its operating instructions at https://www.soilmoisture.com/pdfs/Resource_Instructions_0898-1600_1600%205%20Bar%20Pressure%20Plate%20Extractor.pdf.
- 7.2 For any problems with the transducer of INFIELD7, refer to its operating instructions at <http://cnyhome.cafe24.com/pdf/Infield7Manual.pdf>.

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Table 2: Data sheet for calculations

Ring Sample #	OD soil+R+C (g)	Clean Ring (g)	Clean C (g)	OD soil (g)	Volume (cm ³)	BD (g/cm ³)	Porosity (cm ³ /cm ³)	0.10 bar VWC (cm ³ /cm ³)	0.33 bar VWC (cm ³ /cm ³)	0.90 bar VWC (cm ³ /cm ³)

AD= Air Dried; OD= Oven Dried; C=aluminum Can; BD= Bulk Density
 VWC= Volumetric Water Content; Volume = L*A= 5.10 cm * 19.63 cm² = 100.08 cm³
 Bulk Density (BD) should generally be in the range of 0.90 - 1.70 g/cm³