Low Pressure Soil Water Desorption and Bulk Density

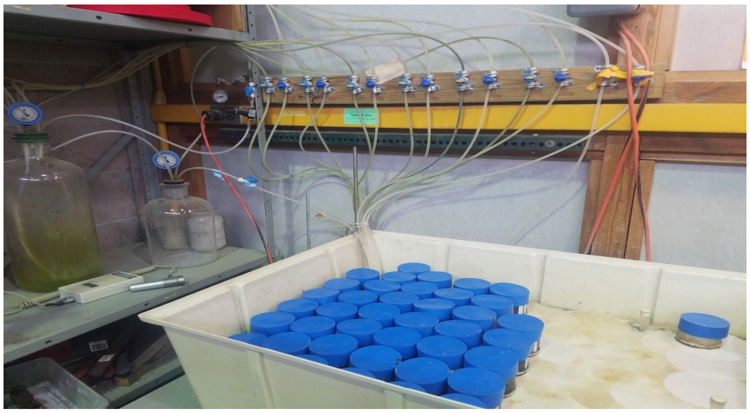


Figure 1. Photo of vacuum jars and switching manifold to remove water from porous ceramic cylinders buried in a bed of silt-sized media.

Background / Strategy:

Soil water desorption curves describe the relationship between soil water content and soil water potential (matric potential) for soils initially wet and sequentially dried. Here, undisturbed soil cores are saturated and subjected to negative matric suction forces using a silica flour soil tension table. After the water in the soil cores achieves equilibrium with the applied suction, samples are weighed to determine water content change from each applied tension step (Cassel and Nielson, 1986). Pore size distributions are also calculated from the resultant data (Topp et al., 1993). Using the oven dry weight of the intact core, the Bulk Density of each sample is presented using 1) the volume of the soil at a typical "field capacity" condition of 0.33bar pressure (BD_{fc}) and 2) the volume of the soil after oven drying to constant weight at 105C (BD_{od}).

Approach:

A soil tension table is used that is outfitted with a suction pump and vacuum regulator attached through a valved manifold to six 200ml volume unglazed porous ceramic cups. These cups are buried in 15cm deep silica flour (effective pore size 60um) with water outflow captured in a vacuum bottle trap. Water is extracted from the silica flour media (and the soil samples upon it) until equilibrium with the applied vacuum is reached. Five buried reference soil tensiometers are used to check *in situ* matric potential versus the gauge reading on the vacuum trap. Two extra Quality Control (QC) soil cores are used with each 60 sample set. These dummy cores have a known equilibrium weight corresponding to the applied suction. They serve as guides to check the apparatus functioning and also act as a gauge to samples attaining equilibrium with each applied suction.

Soil core samples of typically about 250ml volume have their bottom face trimmed smooth. Nylon cloth with 50um mesh is placed on the sample bottom and held in place with a stout rubber band. The upper end of the core is trimmed flush and covered with a loose fitting plastic cap. Soil cores are saturated in a large plastic tray with open 8mm rubber mesh on the bottom. Water depth is increased over 3 days to just to top of the core without overtopping. After 4-7 days, record the weight of the saturated core using the cap on top of the sample as a vessel to retain draining water during the weighing. Place each sample onto a drain cart that has an open 8mm rubber mesh on the bottom with water ponded to 1cm depth. Replace the plastic cap onto the top of each sample.

Allow samples to remain on the gravity table for 3-12 hours to achieve equilibrium water content with the applied gravity water suction (equivalent (in cm) to ½ of the distance from the top of the core to the water surface). Use the plastic cap again to weigh and record the sample weight.

Place the samples onto the tension table using a nylon membrane filter to separate the soil core sample from the silica flour. The media should be completely saturated with the surface soft but not liquid. Set vacuum regulator above vacuum bottle to desired suction. Open valves to allow suction delivery to the media and samples. Allow about 6-10 days for samples to reach equilibrium with the applied suction. Record sample weight with the top cap used beneath the sample.

Each day, record the weight of the reference dummy samples. After several days, the weight change will be no greater than simple evaporation weight loss and the samples are at equilibrium with the applied tension. Remove each sample and record the weight including the plastic top cap as a dish. Re-saturate the sand table media between each tension step by delivering water backwards through the buried porous ceramic cups. A water supply bottle can be placed 150cm above the apparatus to allow gravity to supply the water to the media. Collect the equilibrium core sample weight data from the final suction pressure step, typically 0.33bar. Now, carefully add dry sandblasting sand (125-250um, particle density 1.55g/cm^{-3}) to completely fill the shrinkage void at the top of the soil and along the side of the ring. Screed off the surface flush with the top of the sample sleeve. Reweigh after replacing the plastic cap with an equivalent weight aluminum dish under the sample. Samples can be placed in a 105C oven and dried to constant weight, usually about 3 days. Remove sample and record weight including the aluminum dish below the sample. Again re-fill sample to the top of the sample ring with more sandblasting sand, tapping ring sides to ensure crack filling. Record sample weight including the metal dish.

Bulk density can be calculated on the 0.33bar soil volume basis or oven dry soil volume basis. The oven dry weight of the soil material is the same at both moisture contents (Hao et al., 2008). The volume of the soil material changes due to soil shrinkage. Water contents are all calculated on a gravimetric (mass) basis. Convert to the volumetric basis using the bulk density (Reynolds and Topp, 2008).

Calculate the parameters listed below:

+ antecedent (as-sampled) water content (gravimetric and volumetric)
+ saturated water content (gravimetric and volumetric)
+ gravity-equilibrium (6cm height core: 0.003bar = 3cm tension) water content (gravimetric and volumetric) *tension developed at this step is always 1/2 sample height
+ 0.33bar water content (gravimetric and volumetric)
+ Total (macro, meso, micro) porosity
+ Calculate Available Water-holding Capacity (0.33 to 15bar) *requires pressure plate data collected using pressure chamber equipment for 15bar data
+ BD_{fc} (“field capacity”) based on 0.33bar soil volume
+ BD_{od} (oven dry) based on oven dry soil volume

water potential			pore diameter	porosity
cmH2O	kPa	bars	microns	class
0	0	0	saturation	total porosity
3	0.3	0.003	1000	macro-
10	1	0.01	300	
25	2.5	0.025	120	
50	5	0.05	60	
100	10	0.1	30	field cap.
200	20	0.2	15	
300	30	0.3	10	meso-
400	40	0.4	7.5	
1000	100	1	3	
15000	1500	15	0.2	micro-
			< 0.2	residual

Table 1. The resultant soil water potential in the samples is related to the equivalent pore diameter emptied using the table at left. Porosity class is also given. Macroporosity (pores greater than 1mm diameter) is measured after the 6cm tall soil core drains to equilibrium on the gravity table.
Note that field capacity is referenced at 0.1bars (100cm tension). Often 0.33bars (330cm tension) is used as the reference for field capacity.

References:

Topp GC, Galganov YT, Ball BC, Carter MR. Soil water desorption curves. Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, FL. 1993:569-79.

Hao X, Ball BC, Culley JL, Carter MR, Parkin GW. Soil density and porosity. Soil sampling and methods of analysis. 2, CRC Press, Boca Raton, FL. 2008:743-60.

Reynolds, W. D., & Topp, G. C. Soil water desorption and imbibition: tension and pressure techniques. Soil sampling and methods of analysis, 2, CRC Press, Boca Raton, FL. 2008: 981-1005.

Cassel, D. K., & Nielsen, D. R. (1986). Field capacity and available water capacity. Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods, 5, 901-926.

Culley, JLB. (1993) Density and compressibility. In: Carter, M.R., Ed., Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, FL, 1993: 529-549.

Objective:

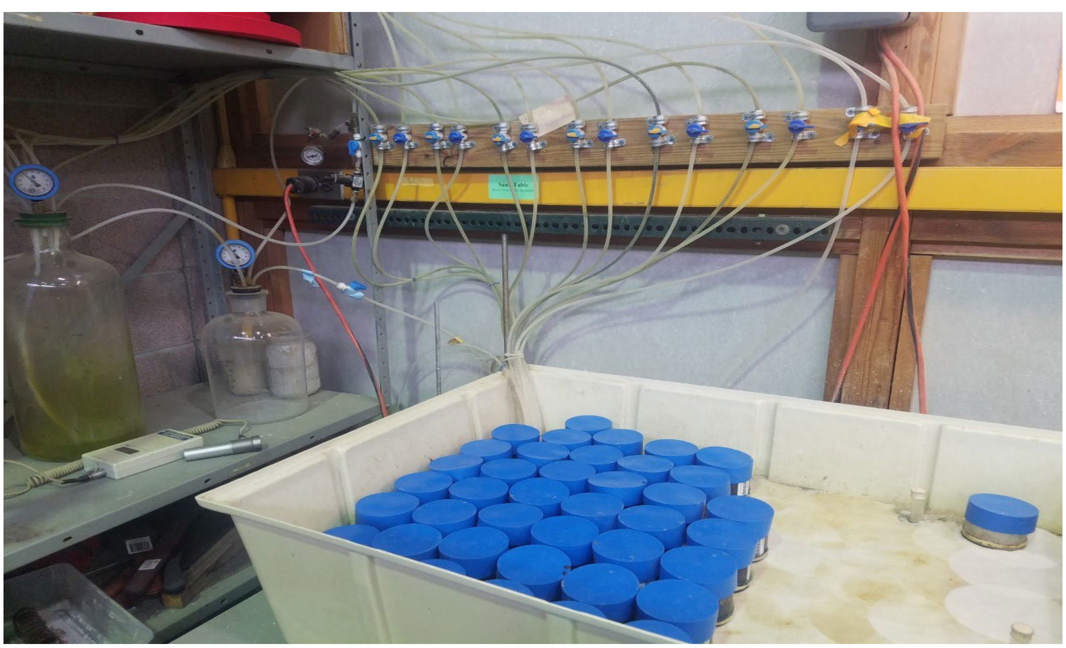
Undisturbed soil cores can be desorbed on a tension table from saturation to 0.33bars. Gravity drainage of saturated cores on a drain cart at equilibrium empties pore diameters > 1mm (macropores) (Table 1). Mesopore data (pore diameter between 1mm (1000µm and 10µm) is obtained from then desorbing the soil cores in one step to 0.33 bars (Table 1). Data collected allows for direct measurement of gravimetric (mass based) water content.

Bulk density on a field moist volume basis (called "field capacity") at 0.33bar (Ψ_{fc}) or oven dry volume basis (Ψ_{OD}) can be derived. Glass beads (dry sandblasting sand with particles 125-250um in diameter, particle density $1.55g/cm^{-3}$) are used to determine the volume change due to water loss 1) during sand table desorption to 0.33bar and 2) from oven drying (Culley, 1993). Volumetric water content data can be calculated from these data. Calculation of porosity and pore size distribution can be calculated from this data, with porosity classes being given in Table 1 above.

NOTE: For quarantined soils, use quarantined procedures listed throughout the Cornell Soil Health Laboratory Standard Operating Procedures. Contain all soil material and accessory material for storage in autoclave bags for destruction. Water extracted from undisturbed cores is collected and sterilized with a 10% bleach solution for 30 minutes. Use 10% bleach solution or 70% alcohol for surface sterilization.

Materials and Equipment:

Figure 2. The suction sand table apparatus uses a vacuum pump to maintain surplus vacuum in a string of vacuum jars beneath the table. The silica flour media (silt-sized) is outfitted with six buried unglazed porous ceramic cups. These cups are connected via a switching manifold to a vacuum regulator on a vacuum water trap (above and at left in Figure 2, below). Each ceramic cup is also fitted with a switchable second tube to allow new water (source just above the top of Figure 2, below) to travel through the porous cups to saturate the media and raise the free water surface.



After all data is recorded on the Sand Table data sheet in the laboratory (Table 1. I, below), transcribe into an Excel spreadsheet (Table 1. II and 1. III, below). In each set of 60 samples that are run, two samples are included as soil standards which are run as a check or quality control. Columns are dedicated to identifying the samples and their locations during the testing. Other columns list the data to be recorded with instructions for including accessory weighing dishes. Enter all of the raw lab data and drag down the formulas from the top row of the EXCEL spreadsheet.

Table 1. Soil core datasheet and with parameter calculator (see next three pages).

I. **Columns A-J.** Record data here. Use different lab constants as appropriate.

lab apparatus constants	
plastic ring, rubber band, v	38.4g
volume soil ring	322.5cm^3
blue evaporation cap	12g
metal drying dish	12g
density glass beads	1.55g/cm^3

column A	column B	column C	column D	column E	column F	column G	column H	column I	column J
			voile+ring	saturated wt. (g)	3-hour wt. (g)	0.33 bar wt. (g)	**add beads (1)** 0.33 bar wt. (g)	**with beads (1)** oven dry wt. (g)	**add more beads with beads (2)** oven dry wt. (g)
order	ID	Cornell ID	Antecedent wt.	WITH blue dish	WITH blue dish	WITH blue dish	WITH metal dish	WITH metal dish	WITH metal dish
1	dummy	SH3	571.5	609.7	605.2	575.3	595.3	475.0	494.2

II. **<u>Columns K-Y.</u>** Calculations shown of soil core volume at different water contents yielding a water-content specific bulk density. Theta M gravimetric water contents of the soil cores are also determined.

column K	column L	column M	column N	column O	column P	column Q	column R	column S	column T	column U	column V	column W	column X	column Y
weight in grams, volume in cm^3											theta M g H2O/ g dry soil	theta M g H2O/ g dry soil	theta M g H2O/ g dry soil	theta M g H2O/ g dry soil
wt. of beads 0.33	wt. of beads oven dry	vol. of beads 0.33	shrinkage % at 0.33bar	vol. of beads oven dry	shrinkage % at oven dry	vol of soil 0.33	vol. of soil oven dry	**oven dry soil wt bare core**	BD 0.33 basis	BD ovendry basis	**antecedent**	**saturated**	**0.3kPa**	**33 kPa**
(H20-G20)	(J20-I20)	K20/1.55	(M20/322.5)*100	L20/1.55	N20+(((O20/(Q20))*100))	322.5-M20	322.5-M20-O20	J20-K20-L20-38.4-12	S20/Q20	S20/R20	(D20-38.4-S20)/S20	(E20-38.4-12-S20) /S20	(F20-38.4-12-S20) /S20	(G20-38.4-12-S20) /S20
20.0	19.2	12.9	4.0	12.4	8.0	309.6	297.2	404.6	1.31	1.36	0.32	0.38	0.37	0.30

III. **Columns Z-AI.** Calculations of Theta V volumetric water contents based on each bulk density water content basis is shown. Macro- and mesoporosity is calculated.

theta $V_{0.33}$ volumetric water content field capacity soil volume basis				theta $V_{oven\ dry}$ volumetric water content oven dry soil volume basis					
column Z	column AA	column AB	column AC	column AD	column AE	column AF	column AG	column AH	column AI
theta $V_{0.33}$ cm^3 H2O/ cm^3 dry soil	theta $V_{0.33}$ cm^3 H2O/ cm^3 dry soil	theta $V_{0.33}$ cm^3 H2O/ cm^3 dry soil	theta $V_{0.33}$ cm^3 H2O/ cm^3 dry soil	theta $V_{oven\ dry}$ cm^3 H2O/ cm^3 dry soil	theta $V_{oven\ dry}$ cm^3 H2O/ cm^3 dry soil	theta $V_{oven\ dry}$ cm^3 H2O/ cm^3 dry soil	theta $V_{oven\ dry}$ cm^3 H2O/ cm^3 dry soil	cm^3 H2O/ cm^3 dry soil	cm^3 H2O/ cm^3 dry soil
antecedent	saturated	0.3kPa	33 kPa	antecedent	sat.	0.3kPa	33 kPa	macro-porosity	meso-porosity
V20*T20	W20*T20	X20*T20	Y20*T20	V20*U20	W20*U20	X20*U20	Y20*U20	AA20-AB20	AB20-AC20
0.42	0.50	0.49	0.39	0.43	0.52	0.51	0.40	0.01	0.10