



Standard Test Methods for Saturated Hydraulic Conductivity, Water Retention, Porosity, Particle Density, and Bulk Density of Putting Green and Sports Turf Root Zones¹

This standard is issued under the fixed designation F 1815; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods cover the measurements of saturated hydraulic conductivity, water retention, porosity (including distribution of capillary and air-filled porosity at a known matric potential), and particle and bulk densities on root zone mixes to be used for construction and topdressing of golf course putting greens including United States Golf Association (USGA) recommended greens or other highly trafficked turf-grass areas.

1.2 Water retention is not a required measurement for USGA Recommended greens. Its inclusion in these test methods is for the benefit of those who wish to continue to obtain such data. Likewise, bulk density is no longer a physical parameter required in the evaluation of USGA root zone mixes, but it must be determined for calculation of total and capillary porosity.

1.3 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to its use.*

2. Referenced Documents

2.1 ASTM Standards:

D 854 Test Method for Specific Gravity of Soils²

F 1647 Test Method for Organic Matter Content of Putting Green and Sports Turf Root Zone Mixes^{3,4}

¹ These test methods are under the jurisdiction of ASTM Committee F-8 on Sports Equipment and Facilities and are the direct responsibility of Subcommittee F08.64 on Natural Playing Surfaces.

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² These test methods are designed for testing sand-based root zone mixes used for the construction of USGA and other high sand greens and sports fields. It is not intended for use on fine or medium textured soils, for example, loams.

³ *Annual Book of ASTM Standards*, Vol 04.08.

⁴ *Annual Book of ASTM Standards*, Vol 15.07.

3. Summary of Test Method

3.1 *Test Method A*—Saturated hydraulic conductivity is determined on compacted, saturated soil cores. Water flow through the core is maintained at a constant hydraulic head until a steady flow rate is achieved, at which time aliquots of the outflow are collected.

3.2 *Test Method B*—Water retention is obtained at a matric potential that corresponds to the root zone profile depth by extracting the water from a prepared core by means of a tension table or other water extraction apparatus. When the weight reaches equilibrium, the weight is recorded. The core is oven dried at 105° C, until a constant weight is obtained. Water retention is calculated on an oven dried basis. Bulk density is calculated from the soil dry weight and volume.

3.3 *Test Method C*—Particle density is used for calculating total porosity. Two methods are acceptable to use; one using glass pycnometers (Test Method C-1), the other using an air comparison pycnometer (Test Method C-2).

3.4 *Test Method D*—Total porosity is calculated from the bulk density and particle density.

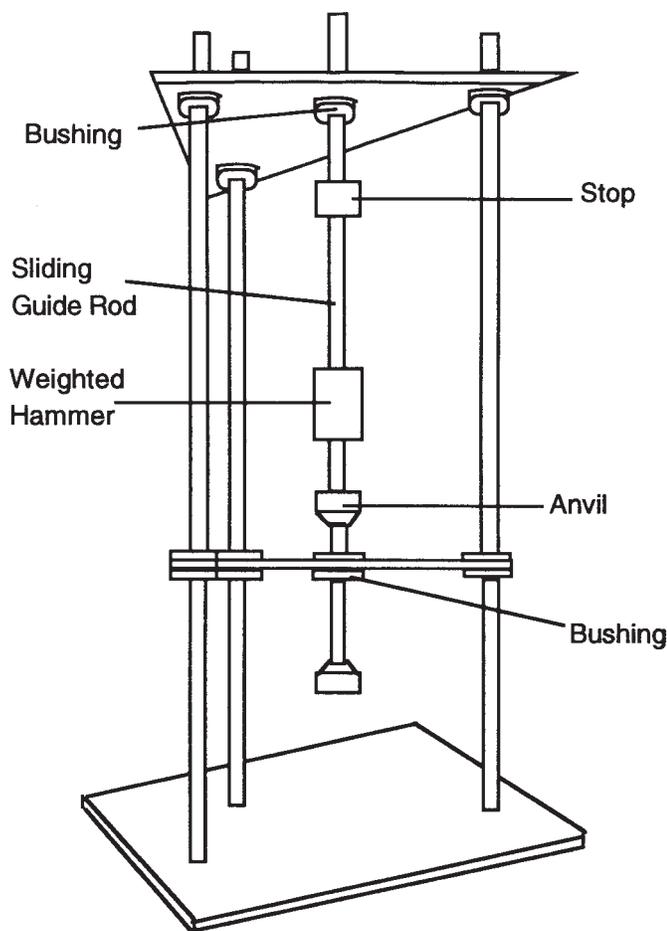
3.5 *Test Method E*—Capillary porosity is calculated from the bulk density and water retention information. Air-filled or aeration porosity is calculated from the difference of total and capillary porosity.

4. Apparatus

4.1 *Cylinders*, made of metal, PVC, or similar rigid materials shall have an inside diameter of 51 or 76 mm (2 or 3 in.), and a minimum height of 76 mm (3 in.).

4.2 *Compactor*, shall be such as to exert a total potential energy of 3.03 J/cm² (14.3 ft lb/in.²) across the surface cross sectional area of the core. Fig. 1 shows an example of such a device where a weighted hammer is dropped 15 times from a height of 305 mm (12 in.). A 51 mm (2 in.) diameter core will require 15 drops of a 1.36 kg (3 lb) hammer from a height of 30.5 cm (12 in.). A 76 mm core will require 15 drops of a 3.02 kg (6.7 lb) hammer from a height of 12 in.

4.3 *Permeameter*, capable of maintaining a constant hydraulic head for several hours.



NOTE 1—It has been found that 15 drops of the hammer from a height of 12 in. (as measured from the bottom of the weight to the top of the anvil) will produce a degree of compaction comparable to a severely compacted putting green, provided the soil contains moisture approximating field capacity.

FIG. 1 A Suggested Impact-Type Compactor to Produce a Total Dynamic Energy of 3.03 J/cm² Across the Surface Cross-Sectional Area of the Core

4.4 *Tension or Porous Plate Apparatus*, capable of extracting water out of the cores at a matric potential of up to - 4kPa (40 cm tension). Fig. 2 shows an example of a tension table.

4.5 *Oven*, capable of maintaining a constant temperature of 105° C.

4.6 *Pycnometer or Specific Gravity Bottle (for Test Method C-1)*—A small flask with a capacity of 50 mL. The pycnometer should have a ground glass stopper with a small hole in it to allow the escape of air. A volumetric flask with a 100 mL capacity may also be used, but a larger sample size will have to be used to compensate for the decrease in precision of measuring the fluid volume.

4.7 *Air Comparison Pycnometer (for Test Method C-2, Micromeritics Multivolume Pycnometer Model 1305)*, capable of accepting a 10 to 35 cm³ sample volume and measuring its volume based on pressure:volume relationships.

4.8 *Cylinder of Helium (for Test Method C-2)*, and associated pressure regulator and tubing as specified by pycnometer manufacturer.

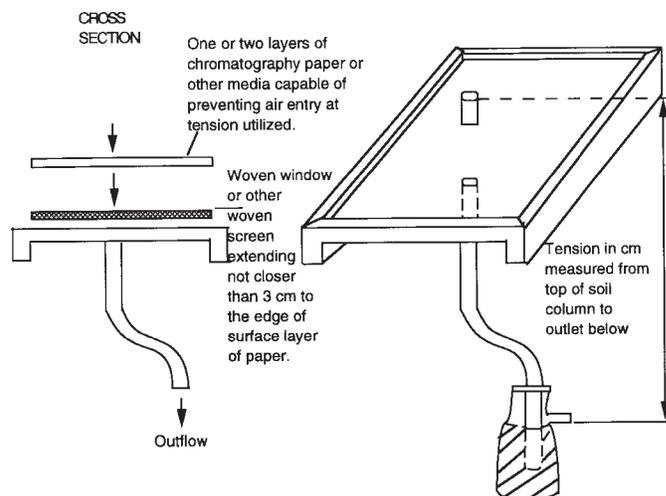


FIG. 2 Suggested Tension Apparatus Capable of Extracting Water out of the Soil Cores

4.9 *Calibration Standard (for Test Method C-2)*—A steel ball of known volume and density.

4.10 *Balance*—A balance sensitive to 1 mg (0.001 g) should be used with pycnometers. A balance with sensitivity to 10 mg may be used with volumetric flasks.

4.11 *Thermometer*, accurate to 0.5° C.

4.12 *Sieves*, No. 4 (4.35 mm) or No. 5 (4 mm).

5. Preparation of Samples

5.1 Premixed Samples:

5.1.1 The cylinders should be prepared by attaching a double layer of cheesecloth or other suitable cloth material with a rubber band onto the bottom of each cylinder. The cheesecloth or other material should be trimmed to a consistent size prior to or after placement on the cylinder. Weigh and record the weight of each cylinder.

5.1.2 Screen the root zone mixture through a No. 4 or No. 5 sieve to remove peat clods and other debris. Peat clods should be broken up and returned to the sample.

5.1.3 Place moistened root zone mix into the cylinder, tapping gently on a firm surface as mix is added. If dry, moisten by misting with water to reduce segregation of particles during handling. Add sufficient quantities of mix to fill the cylinder. The intent here is to have the surface of the compacted soil within 10 mm from the top, but not above the lip of a 76 mm height cylinder. To ensure a sufficient height (66 to 76 mm) of the compacted soil, a cylinder longer than 76 mm can be used or a second cylinder of the same diameter and 2 cm or greater in height can be secured to a 76 mm test cylinder prior to filling and compaction of the sample. This cylinder is removed after compaction.

5.1.4 Place the cylinder in a pan of water and allow it to saturate from the bottom up. Be careful not to splash any water onto the soil surface. Allow the core to saturate for 30 to 60 min. Hydrophobic soils should be moistened by misting with water and stirring prior to packing the cylinders.

5.1.5 Place the cylinders on a tension table or other water extracting device, set to remove water at matric potential that corresponds to the depth of the profile (See Fig. 2 for proper

measurement). For example, samples for a USGA green with a 30 cm deep root zone should have water extracted at a matric potential of -3 kPa. Leave sample cores on the tension table for at least 16 h. Cover the tension table and cylinders with a plastic sheet to minimize evaporation from the surface of the cores and the tension table.

5.1.6 Place the cylinder onto the base of the compactor, and drop the weight 15 times from a height of 305 mm (12 in.).

5.1.7 Remove the upper cylinder, if one is used. If the level of the mix is above the top of the lower cylinder, remove the mix, repack the cylinder with new mix, resaturate the sample, bring to - 3 kPa matric potential or another appropriate potential and recompact the sample. **Do not shave off the top of the soil.** If the level of the mix is below the edge of the cylinder, measure the length of this depression to the nearest 0.1 cm (1 mm). Subtract this value from the height of the cylinder to determine length of the soil column (L). Record this number (cm).

5.1.8 Calculate the volume of the soil column as follows:

$$V = L \times A \tag{1}$$

where:

L = length of the soil column (to the nearest 0.1 cm), and
 A = cross sectional area of the column ($A = \pi r^2$).

5.2 Laboratory Mixed Samples:

5.2.1 Root zone mixes are nearly always mixed on a volume basis. Use a measuring device such as a graduated cylinder or small beaker for measuring sand and soil volumes.

5.2.2 Peat volumes should be measured in a loose state. A loose state of peat can be obtained by passing the peat through a No. 4 or No. 5 sieve. The sample should be scooped from the loose peat and measured to the desired volume without compacting the peat sample.

5.2.3 Thoroughly mix the sand, peat or soil, or all of these, to the desired volume ratios.

5.2.4 Determine percent organic matter using one of the methods in Test Method F 1647 to quantify organic matter content on a weight basis. This value and the method used should be reported so that field checks of mixes can assure that the mix corresponds to that developed in the laboratory.

5.2.5 Follow 5.1.1-5.1.8 for sample preparation.

6. Quality Assurance/Quality Control

6.1 A minimum of two, and preferably three replicates of each sample should be included for all measurements.

6.2 A well-characterized standard root zone sample should also be included in each and every run of all physical parameters.

TEST METHOD A—SATURATED HYDRAULIC CONDUCTIVITY⁵

7. Procedure

7.1 Place the compacted sample into a pan of water and saturate from the bottom up.

7.2 Place the cylinder with mix onto the permeameter and begin running water through the sample. Tap water may be used. Set the permeameter to a known hydraulic head. For set ups where the water flows downward from the top, the hydraulic head (h) is measured from the bottom of the soil column to the water level above the soil (see Fig. 3). Record this value (to the nearest 0.1 cm).

7.3 Measure and record the water temperature (°C).

7.4 After a time when a constant flow rate is confirmed, place a collection bottle, flask, or beaker at the outflow point of the cylinders and begin collecting the outflow. Collect the outflow for a specific period of time, the time based on the rate of flow. Collection of one or more samples over a 30 min period is suggested.

7.5 Measure the effluent and record in cm^3 collected over time period, t .

8. Calculation

8.1 Calculate the saturated hydraulic conductivity as follows:

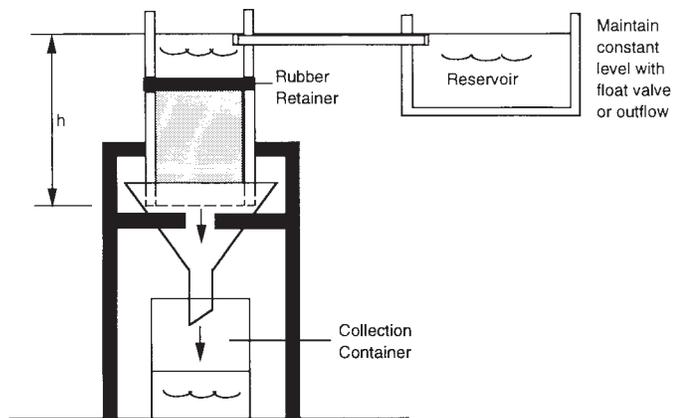
$$K_{sat} = QL/hAt \tag{2}$$

where:

- K_{sat} = saturated hydraulic conductivity (cm/h^{-1}),
- Q = quantity of effluent collected (cm^3) in period of time (t),
- L = length of soil column (cm),
- h = hydraulic head (cm),
- A = cross sectional area of the soil core (cm^2),
- t = time required to collect Q (hour).

8.2 Correct the saturated hydraulic conductivity for the viscosity of water to that for 20°C (68°F) by multiplying K_{sat} by the ratio of the viscosity of water at the test temperature to the viscosity of water at 20°C.

8.3 Divide K_{sat} by 2.54 to convert cm/hr to in/hr , if desired.



NOTE 1—The hydraulic head (h) is measured from the bottom of the soil column to the water level above the soil.

FIG. 3 Suggested Permeameter Setup to Determine Saturated Hydraulic Conductivity

⁵ Procedures for saturated hydraulic conductivity, water retention, porosity, and bulk density were adapted from procedures published in *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods*; American Society of Agronomy Monograph No. 9, Part 1, Second Edition.

TEST METHOD B—BULK DENSITY AND WATER RETENTION

9. Procedure

9.1 Remove the sample from the permeameter, saturate from the bottom, and place on the soil water extractor or tension table set at a matric potential that corresponds to the root zone depth. After 16 h, weigh, correct for water held in cheesecloth⁶, and record the corrected weight as M_w (0.1 g).

9.2 Place the sample in a drying oven set at 105° C and dry for 24 h. If PVC cylinders are used, transfer the sample to a drying cup or pan. Weigh and record weight (0.1 g).

10. Calculation of Bulk Density

10.1 Calculate the bulk density of the soil core as follows:

$$p_b = (M_1 - M_2)/V \quad (3)$$

where:

- p_b = dry soil bulk density (g cm⁻³),
- M_1 = mass of oven-dried soil and cylinder (g),
- M_2 = mass of cylinder (g), and
- V = volume of the soil core (cm³).

11. Calculation of Water Retention

11.1 Calculate the water retention as follows:

$$\Theta_{dw} = \left(\frac{M_w}{M_d} - 1 \right) \times 100 \quad (4)$$

where:

- Θ_{dw} = water retention on dry weight basis (%),
- M_w = net weight determined in 9.1, ((mass moist soil and cylinder) - cylinder mass), and
- M_d = net dry weight mass, ((mass oven dry soil and cylinder) - cylinder mass).

TEST METHOD C—PARTICLE DENSITY

12. Test Method C-1, Glass Pycnometer

12.1 *Calibration of Pycnometers (Taken from Test Methods D 854):*

12.1.1 Clean, dry, and weigh the pycnometer and record the weight. Fill the pycnometer with distilled water at room temperature. Determine the weight of the pycnometer and water W_a and record. Insert a thermometer in the water and determine its temperature T_i to the nearest whole degree.

12.1.2 From the weight W_a at the observed temperature T_i , a table of values of weight W_a shall be prepared for a series of temperatures that are likely to prevail when the weights W_b are determined later (see Note 1). Calculate the values of W_a as follows:

$$W_a \text{ (at } T_x) = (\text{density of water at } T_x / \text{density of water at } T_i) \times (W_a \text{ (at } T_i) - W_f) + W_f \quad (5)$$

⁶ Water held in the cheesecloth can be determined by weighing appropriate sizes of cheesecloth (see 5.1.1). Reweigh the cheesecloth after wetting and allowing it to come to equilibrium at the appropriate matric potential. The correction equals the moist weight minus the dry weight. The correction value must be recalculated if a different cloth type or matric potential is used.

where:

- W_a = weight of pycnometer and water, g,
- W_f = weight of clean, dry pycnometer, g,
- T_i = observed temperature of water, °C, and
- T_x = any other desired temperature, °C

NOTE 1—This test method provides a procedure that is most convenient for laboratories making many determinations with the same pycnometer. It is equally applicable to a single determination. To bring the pycnometer and contents to some designated temperature when weights W_a and W_b are taken, requires considerable time. It is much more convenient to prepare a table of weights W_a for various temperatures likely to prevail when weights W_b are taken. It is important that weights W_a and W_b be based on water at the same temperature. Values for the relative density of water at temperatures from 19 to 30 °C are given in Table 1.

12.2 Procedure Using Glass Pycnometer (Test Method C-1):

12.2.1 Place approximately 10 g air dried sample into the pycnometer, taking care not to spill any of the mix. If a 100 mL volumetric flask is used, use approximately 50 g of sample, then weigh the flask and soil to the nearest 0.01 g. Determine the water content of a duplicate soil sample by drying it at 105 °C.

12.2.2 Add distilled water to fill the pycnometer one half full, or the volumetric flask three quarters full.

12.2.3 Remove entrapped air by either of the following methods: subject the contents to a partial vacuum (air pressure not exceeding 100 mm Hg), or boil gently for at least 10 min while occasionally rolling the pycnometer to assist in the removal of air. Subject the contents to reduced air pressure either by connecting the pycnometer to an aspirator or vacuum pump, or by the use of a bell jar.

12.2.4 Cool heated samples to room temperature.

12.2.5 Fill the pycnometer with distilled water, clean the outside with a clean, dry cloth. Determine the weight of the pycnometer and its contents, W_b , and the temperature in degrees Celsius, T_x , of the contents as described in 4.1.1.

12.3 Calculation of Particle Density Using Test Method C-1:

12.3.1 Calculate the particle density (p_p), based on water temperature T_x , as follows:

$$p_p = W_o / [W_o + (W_a - W_b)] \quad (6)$$

TABLE 1 Relative Density of Water and Conversion Factor K for Various Temperatures

Temperature, °C	Relative Density Correlation of Water	Factor K
18	0.9986244	1.0004
19	0.9984347	1.0002
20	0.9982343	1.0000
21	0.9980233	0.9998
22	0.9978019	0.9996
23	0.9975702	0.9993
24	0.9973286	0.9991
25	0.9970770	0.9989
26	0.9968156	0.9986
27	0.9965451	0.9983
28	0.9962652	0.9980
29	0.9959761	0.9977
30	0.9956780	0.9974

where:

W_o = weight of sample, corrected to oven dry water content,

W_a = weight of pycnometer filled with water at temperature T_x (g), may be taken from the table described in Section 4, and

W_b = weight of pycnometer filled with soil and water at temperature T_x (g).

13. Test Method C-2—Air Comparison Pycnometer

13.1 *Calibration of Air Comparison Pycnometer:*

13.1.1 Following the manufacturer's instructions, calibrate the volume of the empty sample chamber.

13.1.2 Measure the volume of the calibrated steel ball and compare to the known value. If within 0.1 cm³, proceed with the sample analysis. If not within 0.1 cm³, then re-calibrate the instrument or have it serviced.

13.2 *Procedure Using Air-Comparison Pycnometer (Test Method C-2):*

13.2.1 Dry a sample of root zone mix in the oven at 105° C to constant weight.

13.2.2 Weigh the empty sample container to the nearest 0.1 mg; fill the container to three quarters of its capacity with oven dry root zone and reweigh to the nearest 0.1 mg.

13.2.3 Place the weighed and filled sample container in the instrument; purge the sample 8 to 10 times with helium; pressurize the sample to 19.5 ± 0.2 psi; wait 10 to 15 s; read and record the pressure as P_1 ; switch the instrument to the test mode; wait 10 to 15 s; read and record the pressure as P_2 .

13.3 *Calculation of Particle Density Using Test Method C-2:*

13.3.1 Calculate the volume of the sample based on pressure changes, as follows:

$$V_s = V_c - [V_e/(P_1/P_2) - 1] \quad (7)$$

where:

V_s = volume of sample in cm³,

V_e = volume expelled in cm³,

V_c = volume of cell in cm³,

P_1 = pressure 1, and

P_2 = pressure 2.

13.3.2 Calculate the weight of the sample, W_o , as the weight (in grams) of the filled sample container minus the empty weight of the sample container.

13.3.3 Calculate the particle density (p_p) in units of grams/cm³ as follows:

$$p_p = W_o/V_s \quad (8)$$

TEST METHOD D—TOTAL POROSITY

14. Procedure

14.1 *Calculation of Total Porosity:*

14.1.1 Calculate the total porosity of the sample as follows:

$$S_t = \left(1 - \frac{P_b}{P_d}\right) \times 100 \quad (9)$$

where:

S_t = total porosity (%),

p_b = dry soil bulk density (g/cm³), and

p_d = particle density of root zone mix (g/cm³).

TEST METHOD E—PORE DISTRIBUTION

15. Calculation

15.1 Calculate the capillary porosity as follows:

$$\Theta_{vb} = P_b \times \Theta_{dw} \quad (10)$$

where:

Θ_{vb} = volumetric water content at matric potential of interest (capillary porosity),

p_b = dry soil bulk density, and

Θ_{dw} = water retention.

15.2 Calculate the air-filled porosity as follows:

$$S_a = S_t - \Theta_{vb} \quad (11)$$

where:

S_a = air filled porosity,

S_t = total porosity, and

Θ_{vb} = capillary porosity.

16. Report

16.1 Include the following in a dated report:

16.1.1 Sample identification, including volume ratio of laboratory samples,

16.1.2 Percent organic matter (on weight basis) to the nearest 0.1 %, and the method used to determine it,

16.1.3 Saturated hydraulic conductivity to the nearest 0.1 in./h,

16.1.4 Porosity, including distribution of capillary and air-filled to the nearest 1 %,

16.1.5 Matric potential at which pore distribution was determined,

16.1.6 Particle density of the mix(es) to the nearest 0.01g/cc, and

16.1.7 Bulk density of the compacted mix(es), to the nearest 0.01 g/cc.

17. Precision and Bias

17.1 *Precision*—The precision of the procedures for these test methods for measuring saturated hydraulic conductivity, water retention, porosity, particle density, and bulk density is being determined. Parties interested in participating in inter-laboratory test programs should contact Subcommittee F08.64.

17.2 *Bias*—The bias for these measurements is undetermined because there are no reference values available for the materials used.

18. Keywords

18.1 bulk density; particle density; physical properties; pore distribution; porosity; putting green; saturated hydraulic conductivity; sports field; soils; turfgrass; water retention

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