Standard Test Methods for Saturated Hydraulic Conductivity, Water Retention, Porosity, and Bulk Density of Athletic Field Rootzones[1]

This standard is issued under the fixed designation F1815; 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 soil suction), and bulk density on sand-based root zone mixes to be used for construction and topdressing of golf course putting greens including United States Golf Association (USGA) recommended greens, golf course tees, sand-based sports fields, or other highly trafficked turfgrass areas. These test methods are designed for sand-based mixes and are not intended for use with fine or medium textured soils, for example, sandy loams and loams.

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

1.3 *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:*[2]

D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils

D4643 Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating

D4959 Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating

D5550 Test Method for Specific Gravity of Soil Solids by Gas Pycnometer

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

F1647 Test Methods for Organic Matter Content of Athletic Field Rootzone Mixes

3. Summary of Test Method

3.1 *Test Method A*—Saturated hydraulic conductivity is determined on compacted, saturated mix or sand 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 soil suction as defined by the design architect or engineer in the specifications. In lieu of a specification, or if testing for USGA greens, the water retention shall be determined at a soil suction of 30 cm. The water shall be extracted from a prepared core by means of a tension table or other water extraction apparatus. When equilibrium is achieved, 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 mix or sand dry weight and volume.

3.3 *Test Method C*—Total porosity is calculated from the bulk density and particle density.

3.4 *Test Method D*—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

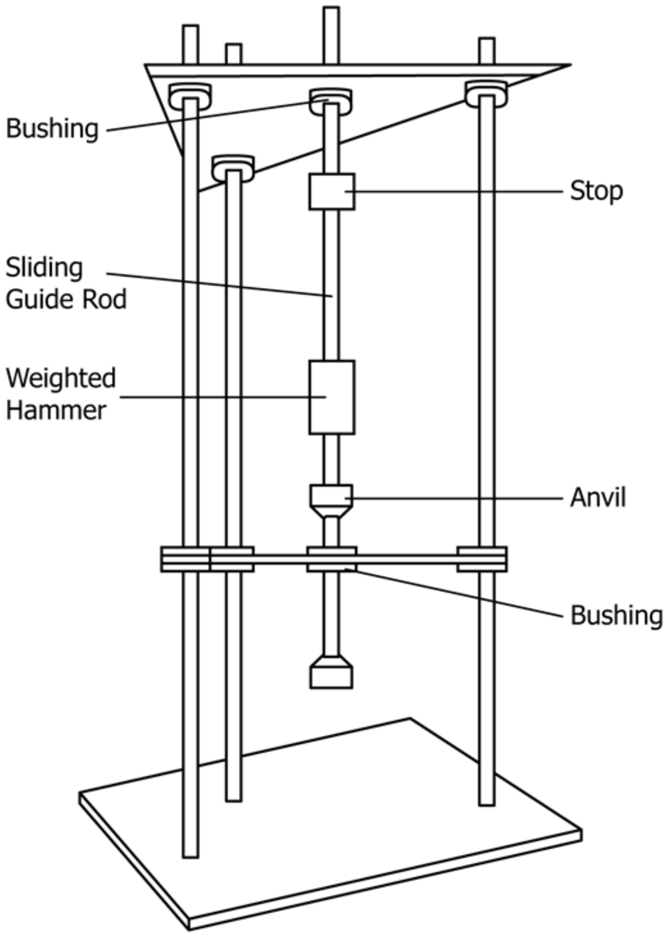
4.1 *Cylinders,* made of metal, PVC, or similar rigid materials shall have an inside diameter of 51 or 76 + 2 mm (2 or 3 + 0.08 in.), and a height of 76 + 2 mm (3 + 0.08 in.).

4.2 *Compactor,* shall be such as to exert a total potential energy of 3.03 J/cm^2 (14.3 ft-lb/in.^{2}) across the 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 + 2 mm (12 + 0.08 in.). A51 mm (2 in.) diameter core will

[1] These test methods are under the jurisdiction of ASTM Committee F08 on Sports Equipment and Facilitiesand are the direct responsibility of Subcommittee F08.64 on Natural Playing Surfaces.

Current edition approved April 1, 2011. Published May 2011. Originally approved in 1997. Last previous edition approved in 2006 as F1815 – 06. DOI: 10.1520/F1815-11.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



NOTE 1—It has been found that 15 drops of the hammer from a height of 305 mm (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/cm^2 Across the Surface Cross-Sectional Area of the Core

require 15 drops of a 1.36 kg (3 lb) hammer from a height of 305 mm (12 in.). A76 mm core will require 15 drops of a 3.02 kg (6.7 lb) hammer from a height of 305 mm (12 in). The drops shall be completed within 1 min. The compactor shall rest on a rigid foundation such as a cube of concrete with a mass of not less than 40 kg (90 lb). Secure the base of the compactor to the foundation. The diameter of the compaction foot should be sufficient to prevent binding with the inside wall of the cylinder, but no more than 2 mm smaller in diameter than the inside diameter of the cylinder. The clearance between bushings and the guide rod should be sufficient to prevent binding, but should be no greater than 2 mm.

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

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

4.5 *Oven,* capable of maintaining a constant temperature of 105 ± 5°C.

4.6 *Balance*—A balance sensitive to 0.1 g.

4.7 *Thermometer,* accurate to 0.5°C.

4.8 *Sieves,* 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, including brass, stainless steel, or fiberglass, 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. 5 (4 mm) sieve to remove peat clods and other debris. Peat clods should be broken up and returned to the sample.

5.1.3 In mixes containing peat or other organic amendments, determine percent organic matter using one of the methods in Test Methods F1647 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 be made to assure that the mix corresponds to that developed in the laboratory

5.1.4 The gravimetric water content of the sample shall be determined by a referenced (Test Methods D2216, D4643, D4959) or other appropriate method. The water content of the sample shall be adjusted to 8 + 0.5 % by adding water to the sample by misting if the antecedent water content is below 8 %, or by air drying the sample if the antecedent water content is above 8 %. Water content is expressed on a dry weight basis ((wt. water/wt. dry soil) × 100).

5.1.5 Place moistened root zone mix into the cylinder, tapping gently on a firm surface as mix is added. Add sufficient quantities of mix to fill the cylinder. The intent here is to have the surface of the compacted mix or sand within 10 mm from the top, but not above the lip of a 76 mm height cylinder. If the level of the compacted mix is above 76 mm or below 66 mm, remove the mix and repack the cores. To ensure a sufficient height (66 to 76 mm) of the compacted mix or sand, 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.

5.1.6 Place the cylinder in a pan of water and allow it to saturate from the bottom up for at least 30 min, until the mix in the core is visibly saturated. The level of the water in the pan shall be within 2 mm below the top of the cores. Be careful not to splash any water onto the mix or sand surface.

5.1.7 Place the cylinders on a tension table or other water extracting device, set to remove water at the desired soil suction (see Fig. 2 for proper measurement). Samples evaluated for USGA greens should have water extracted at a soil suction of -3 kPa (30 cm). Leave sample cores on the tension table for at least 16 h. Cover the tension table and cylinders with a plastic sheet or similar cover to minimize evaporation from the surface of the cores and the tension table.

5.1.8 Place the cylinder onto the base of the compactor, and drop the weight 15 times from a height of 305 + 2 mm (12+ 0.08 in.).

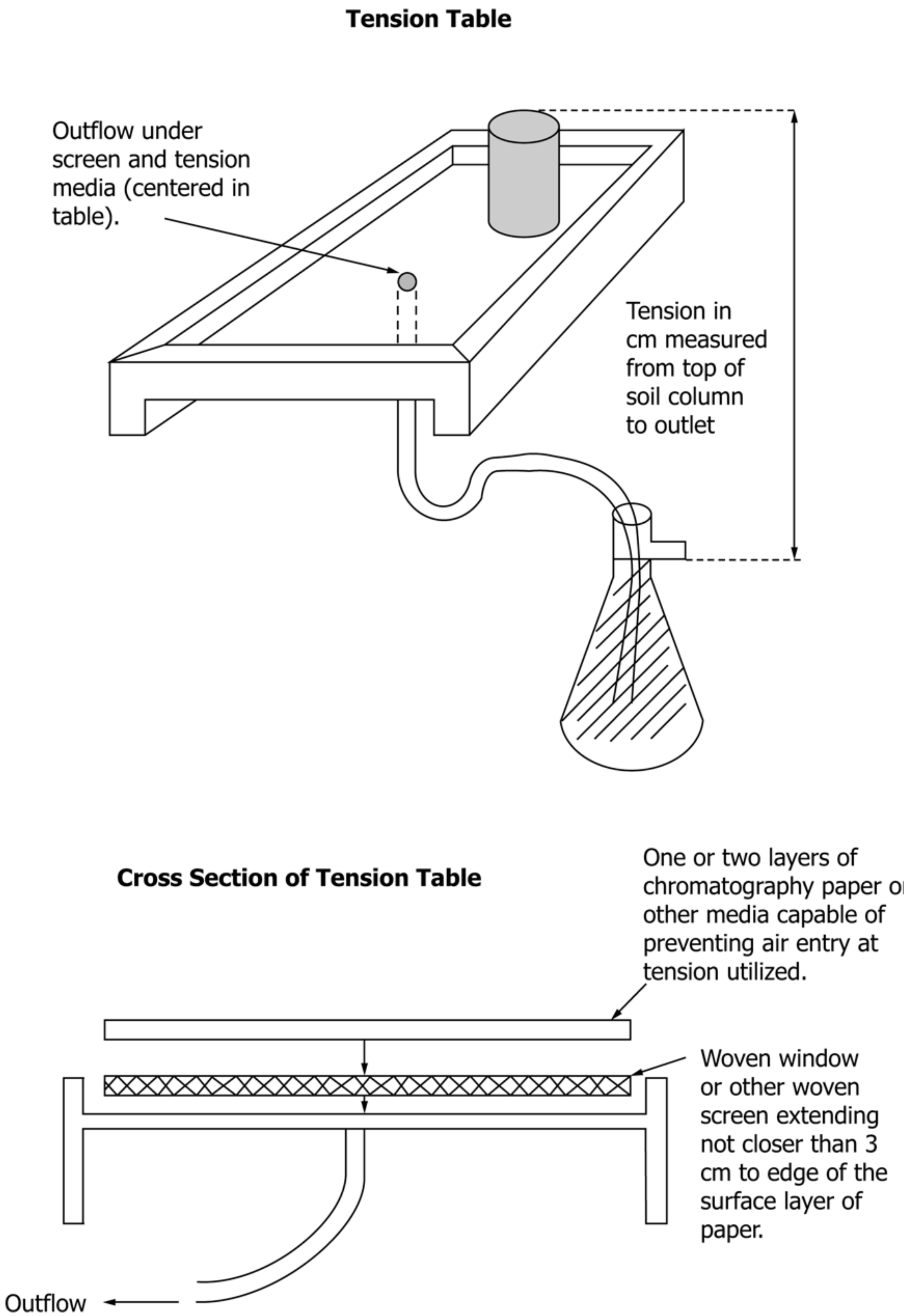
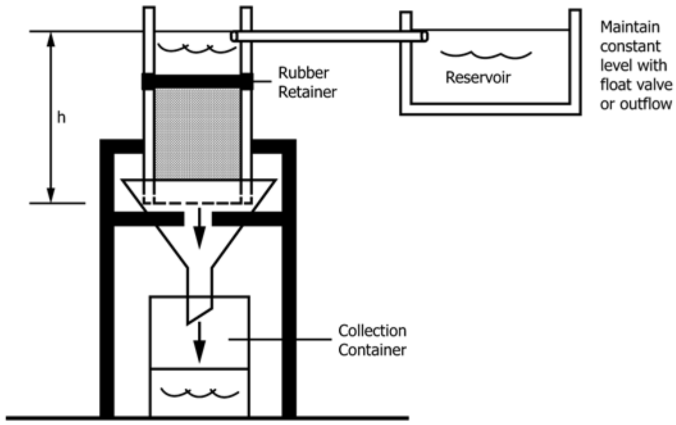


FIG. 2 Suggested Tension Apparatus Capable of Extracting Water out of the Mix or Sand Cores

5.1.9 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 the desired soil suction and recompact the sample. **Do not shave off the top of the mix**. If the level of the mix is below the edge of the cylinder, measure the length of this



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

TABLE 1 Correction Factor (R_t) for the Viscosity of Water at Various Temperatures

Temperature, °C	R_t
15	1.135
16	1.106
17	1.077
18	1.051
19	1.025
20	1.00
21	0.976
22	0.953
23	0.931
24	0.910
25	0.900
26	0.869
27	0.850
28	0.832
29	0.814
30	0.797

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).

5.1.10 Calculate the volume of the mix or sand column to the nearest 0.1 cm^3 as follows:

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

where:

L = length of the mix or sand column (to the nearest 0.1 cm), and

A = cross sectional area of the column ($A = \pi r^2$) to the nearest 0.01 cm^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, soil, peat, or other amendment volumes.

5.2.2 Peat volumes shall 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 shall be scooped from the loose bulk sample and measured to the desired volume without compacting the peat sample. In cases where an organic matter source other than peat is used (for example, compost), prepare and measure the organic matter source as with peat. Inorganic amendments shall be measured in the same manner.

NOTE 1—For quality control purposes, it is advised that moisture and organic matter content be determined on the peat in accordance with Test Methods D2974.

5.2.3 Thoroughly mix the sand, peat or other amendments, or a combination thereof, to the desired volume ratios.

5.2.4 Determine percent organic matter using one of the methods in Test Methods F1647 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 – 5.1.9 for sample preparation.

6. Quality Assurance/Quality Control

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

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

TEST METHOD A—SATURATED HYDRAULIC CONDUCTIVITY[3]

7. Procedure

7.1 Place the compacted sample into a pan of water and saturate from the bottom up. The water level in the pan shall be within 2 mm below the surface of the mix.

7.2 Place the cylinder with mix onto the permeameter and begin running water through the sample. Tap water may be used, and if feasible, heated or cooled to 20°C. If this is not feasible, corrections for the temperature affect on the viscosity of water may be used (see Table 1). 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 mix or sand column to the water level above the mix or sand (see Fig. 3). Record this value (to the nearest 0.1 cm).

7.3 Measure and record the water temperature to the nearest 1°.

7.4 After a time when a constant flow rate is confirmed (+ 10 % over three consecutive measurements), 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 (ml) collected over time period, *t*.

[3] 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 Minerological Methods;* American Society of Agronomy Monograph No. 9, Part 1, Second Edition.

8. Calculation

8.1 Calculate the saturated hydraulic conductivity to the nearest 0.1 cm/h as follows:

$$K_{sat} = QL/hAt \quad (2)$$

where:

K_{sat} = saturated hydraulic conductivity (cm/h),
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 (see Table 1).

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

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 the desired soil suction. After at least 16 h, weigh, correct for water held in cheesecloth, and record the corrected weight as M_W (0.1 g).

NOTE 2—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.

9.2 Place the sample in a drying oven set at 105° C and dry for 24 h or until a constant weight is achieved. If PVC cylinders are used or as an option for metal cylinders, carefully 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 mix or sand 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 mix or sand and cylinder or drying pan(g),
M_2 = mass of cylinder or drying of pan (g), and
V = volume of the mix or sand core (cm^3).

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 mix or sand and cylinder) - cylinder mass), and
M_d = net dry weight mass, ((mass oven dry mix or sand and cylinder) - cylinder mass).

TEST METHOD C—TOTAL POROSITY

12. Procedure

12.1 *Calculation of Total Porosity:*

12.1.1 Calculate the total porosity of the sample to the nearest 0.1 % as follows:

$$S_t = \left(1 - \frac{P_b}{P_d}\right) \times 100 \quad (5)$$

where:

S_t = total porosity (%),
P_b = dry soil bulk density (g/cm^{-3}), and
P_d = particle density of root zone mix (g/cm^{-3}), as determined by Test Methods D5550, D854, or SSSA Pycnometer Method.[4]

TEST METHOD D–PORE DISTRIBUTION

13. Calculation

13.1 Calculate the capillary porosity as follows:

$$\Theta_{vb} = P_b \times \Theta_{dw} \quad (6)$$

where:

Θ_{vb} = volumetric water content at desired soil suction (capillary porosity),
p_b = dry soil bulk density, and
Θ_{dw} = water retention.

13.2 Calculate the air-filled porosity as follows:

$$S_a = S_t - \Theta_{vb} \quad (7)$$

where:

S_a = air filled porosity,
S_t = total porosity, and
Θ_{vb} = capillary porosity.

14. Report

14.1 Include the following in a dated report:

14.1.1 Sample identification, including volume ratio of laboratory samples,

14.1.2 Date of sample receipt, test dates, and report date,

14.1.3 Condition of sample,

14.1.4 Percent organic matter (on weight basis) to the nearest 0.01 %, and the method used to determine it,

14.1.5 Saturated hydraulic conductivity to the nearest 0.1 in./h, nearest cm/h or nearest mm/h,

[4] Flint, A.L., and Flint, L.E., "Particle Density", *Methods of Soil Analysis. Part 4. Physical Methods*, J. H. Dane and P.T. Topp (ed), Soil Science Society of America, Madison, WI, 2002, pp. 229-240, .

14.1.6 Porosity, including distribution of capillary and air-filled to the nearest 0.1 %,

14.1.7 Soil suction at which pore space distribution was determined,

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

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

15. Precision and Bias

15.1 *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 interlaboratory test programs should contact Subcommittee F08.64.

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

16. Keywords

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