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A study conducted by scientists at the University of Southern Illinois was designed to improved the accuracy and repeatable of measuring water movement in prepared putting green rootzone mixes. The study including the creation of a new permeameter (shown above).

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 290 projects at a cost of $25 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Saturated Hydraulic Conductivity of Coarse-textured Rootzone Mixes

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SUMMARY

The USGA recommendation for putting green construction require total porosity (P_t), air-filled porosity (P_a), and saturated hydraulic conductivity (K_{sat}) of the sand mix meet specific values in order to be qualified as a USGA green. Reports indicate that K_{sat} of the same material measured by different technicians and laboratories resulted in large variations that limit the utility of the data. The objective of this study was to develop a procedure for measuring K_{sat} of coarse-textured rooting mixes.

- A new permeameter was developed. The saturation tank and permeameter was combined into a single system hence the soil column could be kept submerged in water at all times to avoid air re-entry into the sample.
- Soil-moisture-density curves of sand and sand mixes showed the optimum sand mix moisture content for packing the sample was between 0.06 and 0.07 g g^{-1}. Research also indicated that if peat moss is used as an amendment, the application rate should not be more than 0.02 g g^{-1} of sand.
- In packing the soil column, the 3-layer approach as described in the Proctor's test, was adopted and modified for column construction.
- Both K_{sat} and bulk density of soil columns constructed by 1-, 2-, and 3-layer approaches were statistically evaluated. Results indicated that the 2- and 3-layer approaches not only could generate adequate firmness comparable to a severely compacted putting green, but also provide consistent and uniform soil columns for K_{sat} measurement. For practical purposes, the 2-layer approach was suggested for soil column construction in order to save time and labor.
- No differences were found in bulk density and K_{sat} between sand columns packed by either 1.32 or 3.02 kg hammers. Since a larger soil sample (76 mm in diameter) was suggested for measuring K_{sat}, the 3.02 kg hammer should be used in packing soil columns.
- The developed procedure was tested by laypersons using the same sand mix and the results showed only about 10% differences in K_{sat} compared to K_{sat} measured by technicians.

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USGA recommendations for putting green construction require that total porosity (P_t), air-filled porosity (P_a) and saturated hydraulic conductivity (K_{sat}) of the sand mix should meet a specific value in order to qualify as a USGA green (11, 12, 13, 14, 15, 16). USGA recommendations were approved by the American Standard of Testing Materials (ASTM) committee in 1997 as the "Performance of USGA Rootzone Testing Analysis Method F1815-97" (1). This method has been widely accepted for evaluating sand mixes for construction and topdressing of golf course putting greens and other high-traffic areas.

Permeameter for measuring K_{sat} of coarse-textured rooting material.

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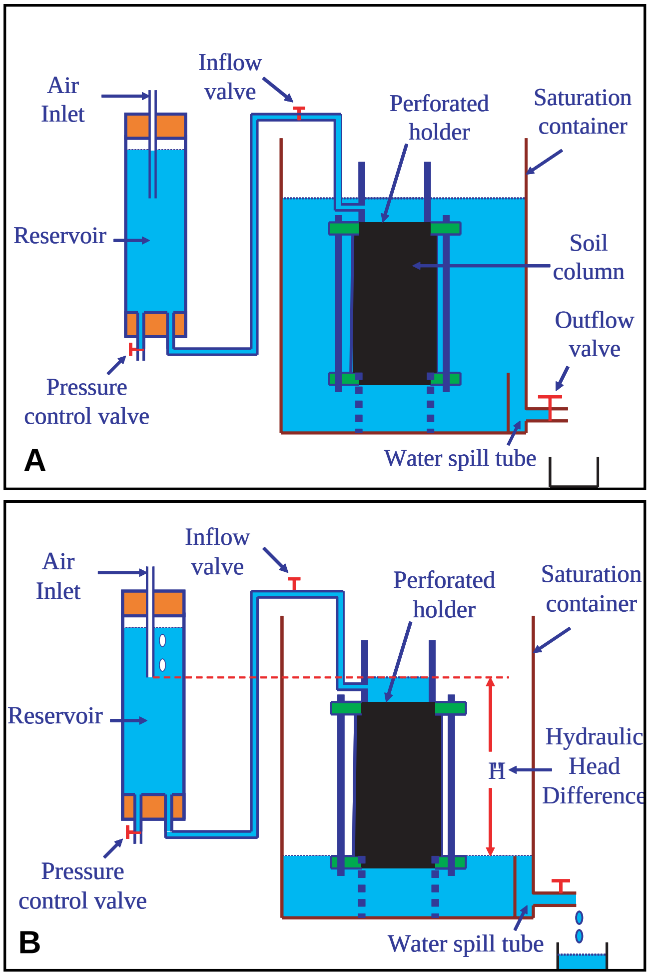

Figure 1. Permeameter for measuring K_{sat} of coarse-textured rooting material developed by Chong (5). Saturation process 1a. Measuring process 1b.

Unfortunately, both USGA recommended laboratory procedures and ASTM F1815-97 do not provide a consistent and clear guideline on soil column construction, as well as measurement of K_{sat}. Questions such as: (1) At what moisture content should the sand mix be controlled in order to achieve a "severe" compaction condition? (2) How should the sand mix be packed so that a uniform column can be achieved? The vague description of the laboratory procedure created confusion among laboratory technicians in measuring K_{sat}.

Sand mixes have very low water retention capacities, hence air can enter rapidly into the sample if the soil core leaves the submerging water after saturation. The permeameter set-up as presented in the ASTM F1815-97 requires removing soil columns out of the water in order to connect it to the inflow and outflow system. Even though the sample is "re-saturated", some air may be unable to escape and remain in the column. When air is trapped in the sample, the column remains unsaturated and K_{sat} measurements will not represent K_{sat} accurately (9).

The objectives of this study were to (1) design a new permeameter which would prevent air re-enter into the soil column, (2) identify the optimal moisture of the sand mix for maximum compaction, (3) develop a consistent procedure of packing soil columns, and (4) evaluate the consistency of K_{sat} obtained by lay persons using the developed method.

Materials and Methods

1. <u>Permeameter</u>

The K_{sat} determinations were conducted using the permeamater by Chong (5). In the newly designed permeameter, the inlet of the sample holder is connected to the reservoir (Figure 1). The saturation tank and the outflow of the permeameter were combined into a single unit. The objective of combining the two together is to avoid removing the sample out of the water. In this way, air re-entry into the sample can be prevented.

During the saturation process, both the inlet and outlet valves remain closed and water is added directly to the saturation tank. After saturation, both inlet and outlet valves of the permeameter are opened allowing the water surrounding the sample in the saturation container to remain constant. The water level at the inlet remains constant due to the water supply from the reservoir. Water is run for 30 minutes and both inflow and outflow water heads are measured. The discharge is collected for 10 minutes and water temperature is measured at the inlet flow. K_{sat} is then calculated using Darcy's equation as described in the USGA recommendations.

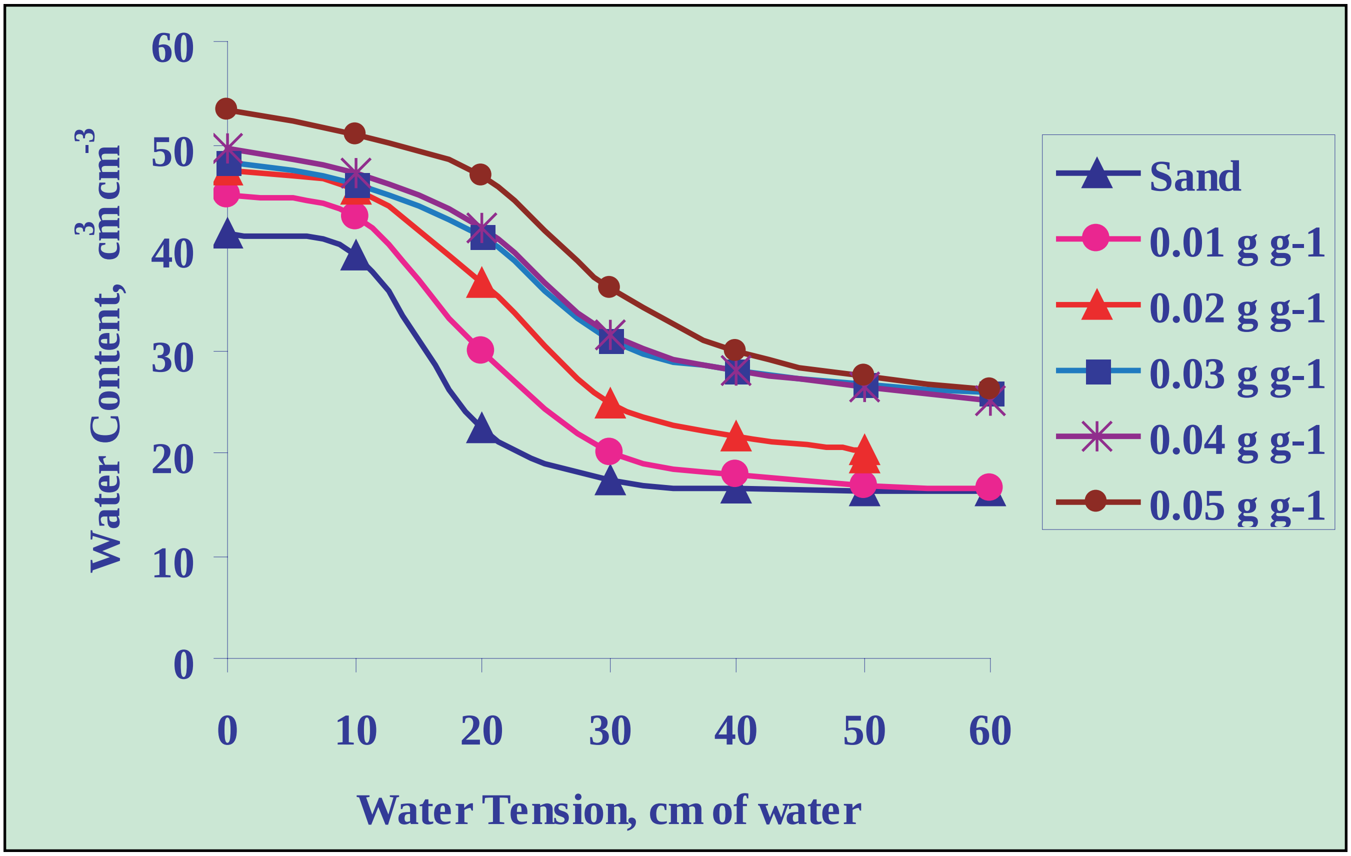

Figure 2. Water retention capacity of sand mixes amended with various amount of peat moss

2. Determination of the amount of peat moss for sand mixes

Peat moss is one of the most popular organic materials used as an amendment in root-zone mixes for golf green construction. The amount of peat moss used in sand mixes varies. The peat/sand ratio of 10:90, 15:85, or 20:80 (by volume) was commonly used for green construction. Scientifically, the peat/sand ratio should be measured by weight since peat moss can be compacted. In the 1993 USGA recommendations, it is suggested to be 0 to 0.05 g g^{-1} (dry weight), and ideally 0.02 to 0.04 g g^{-1}. Sand with higher peat moss will become better rooting mix because of higher water and nutrient retention. However, high peat moss contents may hinder drainage and create an anaerobic condition (4).

In order to determine the most appropriate amount of peat moss to add to sand, a separate experiment was conducted. The objective was to examine the influence of peat moss on K_{sat} and to ensure the sand mix after mixing with peat moss could meet the USGA specification for water movement (i.e., = 150 mm/h, 12). In the experiment, Canadian sphagnum peat moss was used as an amendment, ranging from 0 to 0.05 g g^{-1} (using increments of 0.01 g g^{-1}). Following the USGA recommendation, three soil columns (7.9 cm in diameter and 10 cm long) were constructed for each treatment. In total, 18 soil cores were tested.

After K_{sat} measurements were obstained, moisture retention curves for each soil column were obtained using the hanging water column technique at every -1 kPa increments of water tension down to -6 kPa. After completion, the soil column was weighed and connected to a constant head gasometer for measuring air permeability. Finally, the sample was placed in an oven at 105^{o} C to determine bulk density and the amount of water retained in the column.

Soil water retention curves revealed that peat moss enhanced the sand mix's water retention

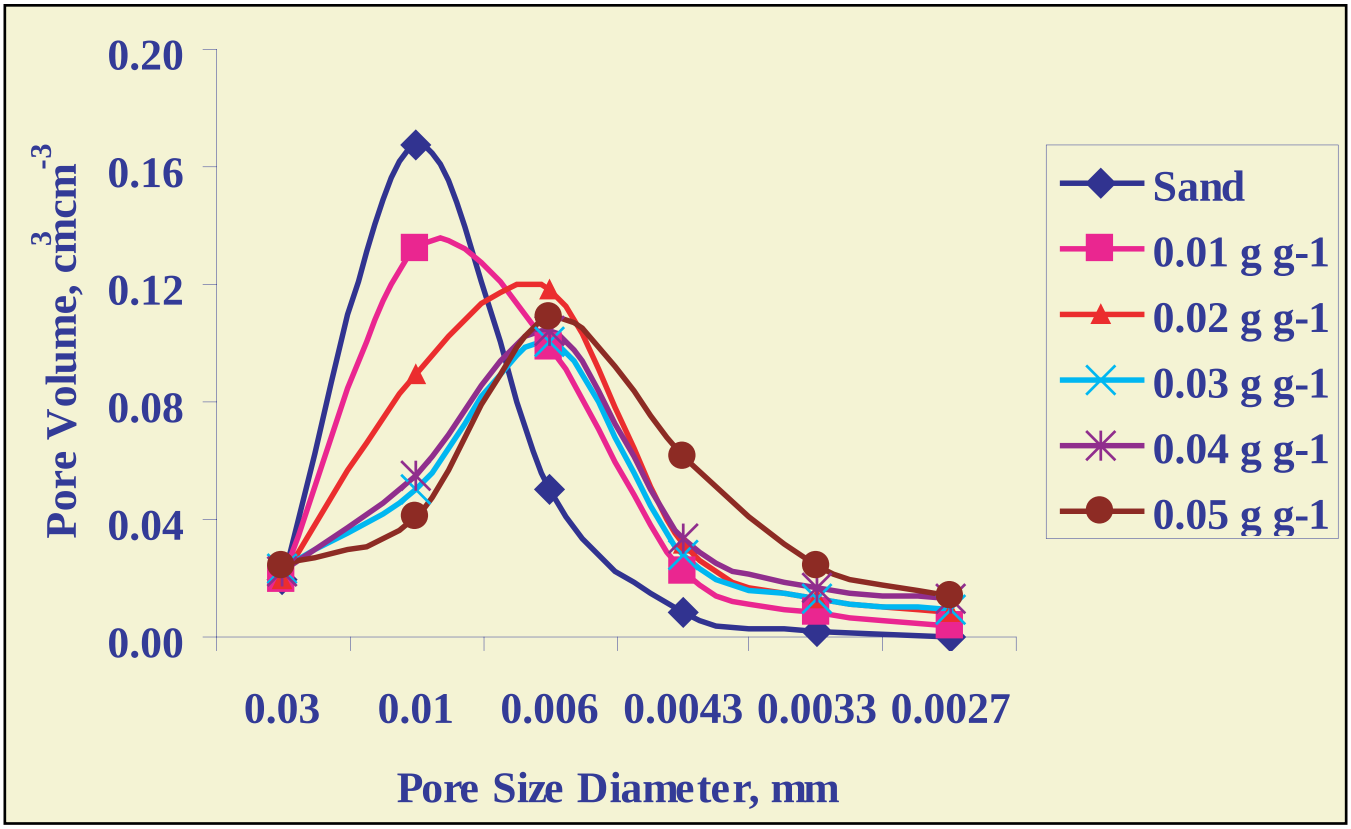

Figure 3. Pore size distribution in sand mixes amended with various amount of peat moss

capacity (Figure 2), but it slowed down water movement through the column. Poor drainage might be attributed to increasing moisture absorption by the peat moss and the alteration of pore configuration and reduction of macropore size and volume in sand mix (Figure 3). Theoretically, any factor affecting the size and configuration of soil pores will influence water movement through the soil column. Under saturated condictions, the flow rate is proportional to the fourth power of pore radius. Therefore, K_{sat} of sand mix decreased as the amount of peat moss increased (Figure 4) .

Figure 4 also revealed that when the amount of peat moss increased over 0.02 g g^{-1}, K_{sat} decreased to about 160 mm h^{-1} which narrowly met the minimum requirement of USGA specifications. Similar response was also observed in air permeability (K_{air}). K_{sat} decreased as peat moss increased and it remained unchanged when the application rate of peat moss was higher than 0.02 g g^{-1}. Therefore, the amount of peat moss should be less than 0.02 g g^{-1} in order to have better water and air circulation in the rootzone. For the purpose of providing a healthy rhizosphere for turf growth, a rate of 0.015 g g^{-1} of peat moss is suggested.

3. <u>Optimal moisture for sand mix compaction</u>

Optimum sand mix moisture for packing can be obtained from soil-moisture-density curves (7). In order to develop the moisture-density curve, another separate experiment was conducted. Both sand and sand amended with 0.015 g g^{-1} peat moss were tested. Each rooting material was divided into six groups. Each group was wetted to different moisture contents (i.e.approximately 0.02, 0.04, 0.06, 0.08, 0.10, and 0.12 g g^{-1}, 6). Ten soil columns were constructed at each moisture level. Both wet and oven-dry weights of the soil columns were measured for determination of water content and bulk density.

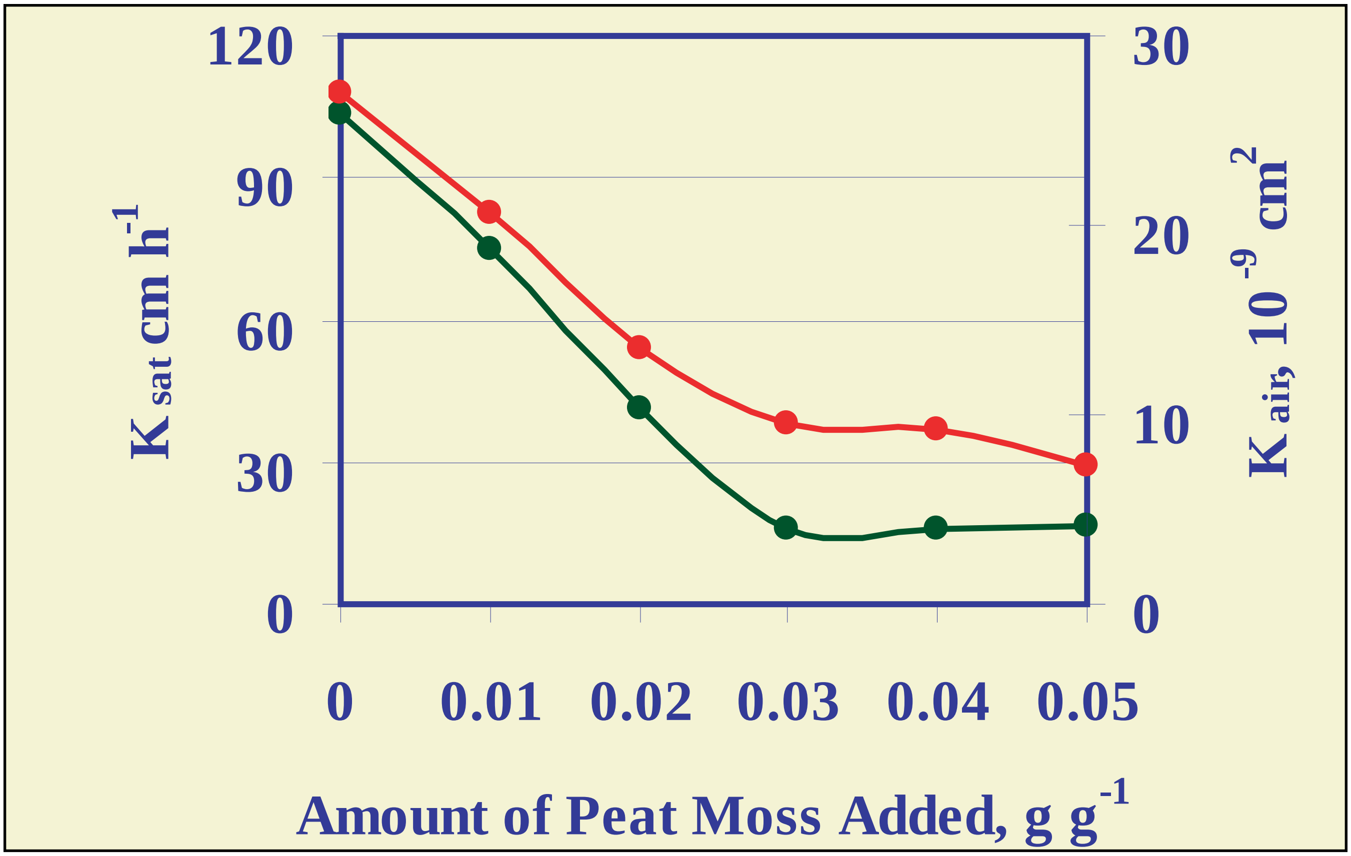

Figure 4. Influence of peat moss on air permeability and saturated hydraulic conductivity of sand mix

Figure 5 shows even though bulk density decreased slightly as moisture content increased, the effect of moisture on bulk density was relatively small compared to that of adding peat moss to sand. Bulk density of sand (1.578 g cm^{-3}) was higher compared to sand mixed with peat. For the sand mix, it was only 1.455 g cm^{-3}, which represented a 7.8 % reduction in bulk density when peat was added.

The coefficient of variation (CV) of bulk density calculated within the same level of moisture is also presented in Figure 5. Sand mix bulk density had a greater CV compared to the bulk densities of sand alone. The CV values of sand mix ranged from 0.76 to 1.23%, while the sand was only 0.22 to 0.55%. The lowest CV value of both sand and sand mix occurred at the water content between 0.05 and 0.07 g g^{-1}. In other words, less variation in bulk density was found within this range of moisture. Therefore, sand and sand mixes with moisture contents between 0.05 and 0.07 g g^{-1} would be best for packing in order to achieve consistency among soil columns and that moisture range is recommended for packing sand and sand mix columns (Figure 5).

4. Soil column construction

Another major cause in the variation of K_{sat} might be attributed to the inconsistency in soil column construction (10). The method of the Proctor test was modified and tested in this study. In the modified Proctor test (denotes as the "SIUC" method, hereafter), two different sizes of hammers were used. The hammers, similar to that described in the ASTM F1815-97, were 1.36 kg (denoted as "$SIUC_1$") and 3.02 kg (denoted as "$SIUC_2$"). The SIUC methods were compared with the methods suggested by the USGA recommendations (13, denoted as "USGA") and the standard method as described in the ASTM F1815-97 (denoted as "ASTM" method). Sand mix columns of all four methods were constructed at the same moisture content.

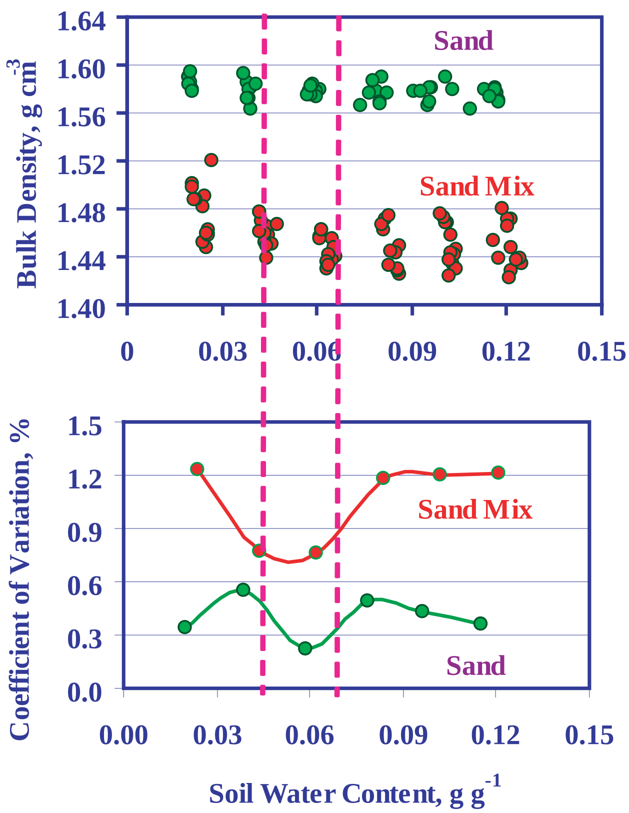

Figure 5. Soil-moisture-density curves of sand and sand mix amended with 0.015 g g^{-1} of peat moss

A 100-mm long by 76 mm (inner diameter) Plexiglas core was used for the soil column construction. In addition, two 25-mm short-rings (with the same diameter of the soil core) were attached to each end of the core with masking tape. On one end of the core, a thin layer of fabric material (80 mesh) together with a perforated Plexiglas disc was attached to hold the sand mix from falling out of the core. For each soil column, a sand mix sample was loaded in three equal layers as suggested in the Proctor test. Each layer received 15 drops of the hammer from a height of 305 mm. After completion, the compacted layer was scratched to about 2 mm deep with a spatula in order to loosen the surface and ensure good contact between layers (17). This process was repeated until the sand mix was about 5 mm below the rim of the top short-ring.

Soil columns were saturated twice prior to measuring K_{sat}. The first saturation was carried out right after each soil column was constructed. The saturation was completed by capillary action by adding 25 mm of water from the bottom of column once every two hours until the wetting front reached a level of about 2 mm below the top surface of the soil column. After saturation, the column was placed on a tension table (at -4 kPa tension) overnight to remove gravitational water. After removing gravitational water from macropores, the columns were compacted again using the same impact hammer using 15 drops from a height of 305 mm. After the second compaction, the two short rings attached to the core were removed. The sand mix was trimmed to the length of soil core. The soil columns were then assembled together with the holders and placed into saturation container for saturation. The second saturation was conducted similar to that of the previous one prior to measuring K_{sat}.

A USGA sand mix (with 0.015 g g^{-1} peat moss with moisture controlled at about 0.06 g g^{-1}) was used to test the packing methods described above. The experiment was conducted by three technicians and each technician constructed four soil columns for each method. Results indicated that for sand alone, even though different hammer weights were used, the mean K_{sat} values produced by the $SIUC_1$ and $SIUC_2$ methods were very similar by all technicians (Table 1). The overall K_{sat} means of $SIUC_1$ and $SIUC_2$ methods were 44.2 and 44.5 cm h^{-1}, respectively, with a coefficient of variation (CV) of less than 7%. This indicates that sand alone was not vulnerable to compaction. But, mean K_{sat} values obtained by the ASTM and USGA methods was about 40% higher than that obtained by the two SIUC methods and had CV values of 11%. Higher CV value indicate higher variability. Therefore, both USGA and ASTM methods could result in less consistent K_{sat} determinations compared to $SIUC_1$ or $SIUC_2$ methods.

For the sand mix, no significant differences were found between the $SIUC_2$ and ASTM methods or among the technicians. Nevertheless, the overall mean K_{sat} of the ASTM method was 21% higher than that of the $SIUC_2$ method. Since the $SIUC_2$ method had the lowest CV (7.9 %) with the highest degree in compaction among all the packing methods, it is recommended for soil column construction. This recommendation is based on the consideration of "representative elementary volume" (2) and consistency of K_{sat}.

Comparison of K_{sat} measured from soil columns constructed by 1-, 2-, and 3-layer approaches

The 3-layer soil column construction, as recommended in the $SIUC_2$ method, is laborious

Technician	Packing Method	Replicates	Minimum (cm/hr)	Maximum (cm/hr)	Mean (cm/hr)	CV (%)
Sand						
Technician 1	1-layer	10	38.65	49.31	44.73	7.8
Technician 2	1-layer	10	40.99	45.43	43.17	3.7
Technician 3	1-layer	10	40.97	52.54	46.02	9.2
Mean			38.65	52.54	44.64	7.6
Technician 1	2-layer	10	32.97	36.13	34.66	3.5
Technician 2	2-layer	10	32.63	38.44	35.38	4.9
Technician 3	2-layer	10	30.73	37.43	34.26	7.1
Mean			30.73	38.44	34.77	5.3
Technician 1	3-layer	10	27.34	33.47	29.04	6.5
Technician 2	3-layer	10	25.45	30.45	26.99	5.1
Technician 3	3-layer	10	28.71	32.96	30.88	5.1
Mean			25.45	33.47	28.97	7.8
Sand Mix						
Technician 1	1-layer	10	27.85	42.16	34.30	19.0
Technician 2	1-layer	10	33.39	42.10	38.76	5.8
Technician 3	1-layer	10	26.51	31.33	29.30	4.8
Mean			26.51	42.16	34.12	16.3
Technician 1	2-layer	10	20.53	24.53	22.64	6.8
Technician 2	2-layer	10	23.20	26.87	24.44	4.3
Technician 3	2-layer	10	23.43	28.29	24.55	5.7
Mean			20.53	28.29	23.88	6.6
Technician 1	3-layer	10	18.31	22.97	21.88	6.2
Technician 2	3-layer	10	20.68	24.39	22.30	5.2
Technician 3	3-layer	10	20.27	24.65	22.59	5.9
Mean			18.31	24.65	22.26	5.7

Table 1. Comparison of K_{sat} measured from sand and sand mix columns constructed by the technicians using the 1-, 2-, and 3-layer approches

and time-consuming. For practical purposes, reducing the number of layers in packing could save time and labor. An experiment was conducted to compare K_{sat} from soil columns constructed by 1-, 2-, and 3-layer approaches.

For the 1-layer approach, all the rooting material was loaded into soil core at one time. In the 2-layer approach, the sample was divided into two equal amounts and then packed following the method described in Walker and Chong (17). The 3-layer approach was essentially the $SIUC_2$ method. Both sand mix and sand were included. Again, the experiment was conducted by three technicians and 10 soil columns were tested per technician by each packing method. In total, 180 samples (2 rooting materials x 3 packing approaches x 10 samples x 3 researchers) were constructed and evaluated.

Results indicated that the K_{sat}s of sand mixes were lower than that of sand alone regardless of packing approaches. Table 1 revealed that sand columns constructed by the 1-layer approach had the highest K_{sat} (for both straight sand and sand amended with peat), followed by the 2- and 3-layer approaches. Overall mean K_{sat} values constructed by the 1-, 2-, and 3-layer approaches for sand rootzones were 44.6, 34.8, and 29.0 cm h^{-1}, respectively. For the sand mix, they were 34.1, 23.9 and 22.3 cm h^{-1}. Even though K_{sat} of sand mix constructed by the 3-layer approach had a lower CV, the difference in mean value between the 2- and 3- layer approaches was only about 7%. For the purpose of saving time and labor, soil column packed by the 2-layer approach should be acceptable and is recommended.

K_{sat} consistency test by laypersons

In order to evaluate the consistency of the developed method (the 2-layer SIUC approach), four students without any knowledge or training in measuring K_{sat} were invited to participate in the test. Prior to the experiment, each student was provided with a handout describing the experimental procedures. In addition, a 30-minute explanation on the equipment operation was given. The same sand mix (at moisture content of about 0.065 g g^{-1}) was used. Each student was asked to prepare three soil columns separately without any discussion among each other.

Results showed three out of four students had the mean K_{sat} value very close to each other

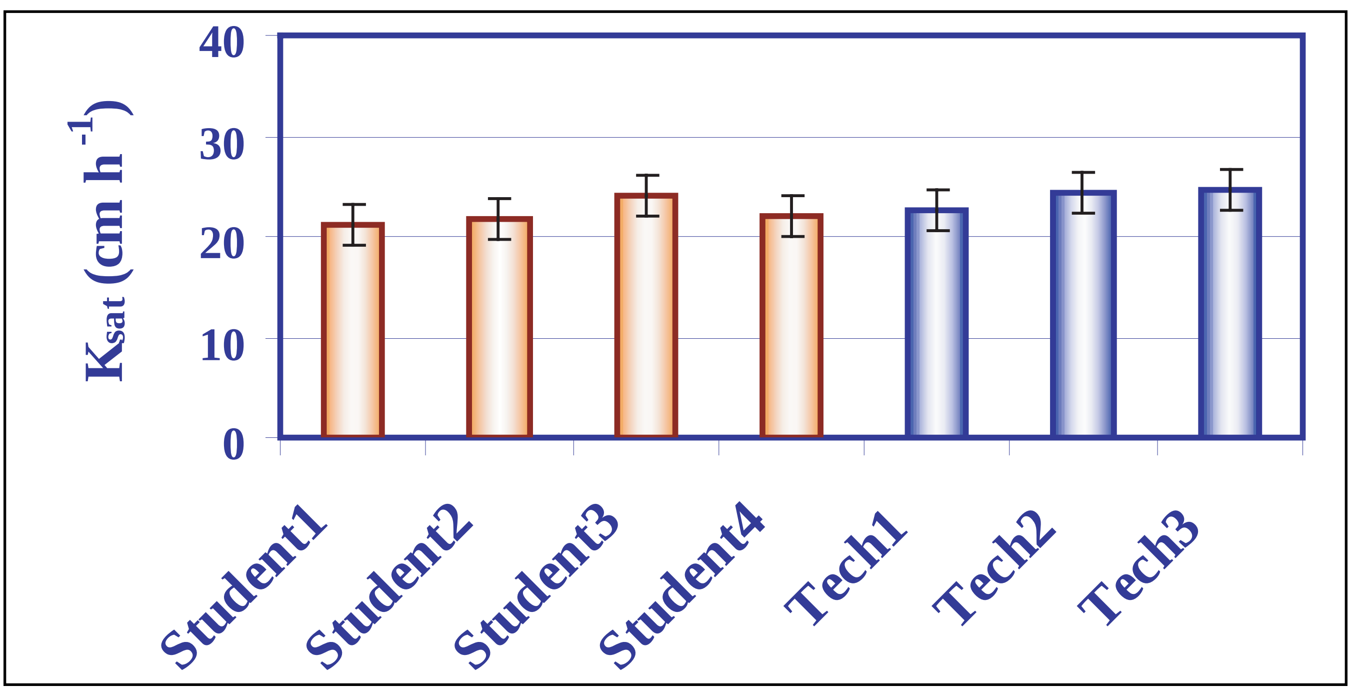

Figure 6. Comparison of mean K_{sat} values obtained by the students and technicians from soil columns constructed by the 2-layer SIUC method

(20.7, 21.9, and 21.1 cm h^{-1}, Figure 6). The fourth student had a K_{sat} of 25.7 cm h^{-1}. However, the CV of the K_{sat} by all the students was less than 7.7%. The mean difference in K_{sat} obtained by the three students was about 10%. For a layperson without any experience in K_{sat} measurements, these results are very encouraging and reinforces the usefulness of these improved procedures.

Acknowledgements

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Literature Cited

1. American Society of Testing Materials. 1997. Standard test methods for saturated hydraulic conductivity, water retention, porosity, particle density, and bulk density of putting green and sports turf root zones. (TGIF Record 96236)

2. Bear, J. 1972. Dynamics of fluids in porous media. American Elsevier Publishing Company, Inc., New York. pp. 764.

3. Bruce, R. R. 1955. An impact type compactor. *Soil Sci. Am. Proc.* 19:253-257.

4. Boyle, M., W. T. Frankenberger, Jr., and L. H. Stolzy. 1989. The influence of organic matter on soil aggregation and water infiltration. *J. Prod. Agric.* 2:290-299.

5. Chong, S.-K. 2003. Measuring saturated hydraulic conductivity of coarse-textured rootzone mixes. p. 5 *In* J. L. Nus (ed.) 2003 USGA Turfgrass and Environmental Research Summary. USGA, Far Hills, NJ. (TGIF Record 93178)

6. Chong, S.-K., R. Boniak, Anquan Zhang, Yanhe Huang, and C.-H., Ok. 2004. Physical properties of green sand mixes amended with various organic composts. *Acta Horticulturae* 661:59-64. (TGIF Record 101688)

7. Das, B. 1989. Soil mechanics laboratory manual. Engineering Press, Inc. San Jose, CA.

8. Ferguson, M. H., L. Howard, and M. E. Bloodworth. 1960. Laboratory methods for evaluation of putting green soil mixture. *USGA Journal and Turf Management* 13(5):30-32. (TGIF Record 23077)

9. Honig, J. A., and J. A. Murphy. 2001. Antecedent water content and air encapsulation effects on physical properties of sand root zone material. *Journal of Turfgrass Science* 77:24-37. (TGIF Record 80270)

10. Miller, R. O., and J. K. Amacher. 2001. Laboratory performance of root zone test methods. *In* Agronomy abstracts. ASA, Madison, WI. (TGIF Record 78718)

11. Moore, J. F. 2004. Revising the USGA's recommendations for a method of putting green construction. *USGA Green Section Record* 42(3):26-28. (TGIF Record 95040)

12.USGA Green Section Staff. 2004. USGA recommendations for a method of putting green construction. WWW.usga.org/turf/course_construction/green_articles/putting_green_guidelines.html (TGIF Record 94463)

13. USGA Green Section Staff. 1993. USGA Recommendations for a method of putting green construction. *USGA Green Section Record* 31(2):1-3. (TGIF Record 26681)

14. USGA Green Section Staff. 1989. Specifications for a method of putting green construction. US Golf Assoc. Far Hills, N. J. 24 p. (TGIF Record 14838)

15. USGA Green Section Staff. 1973. Refining the Green Section specifications for putting green construction. *USGA Green Section Record* 11(3): 1-8. (TGIF Record 17586)

16. USGA Green Section Staff. 1960. Specifications for a method of putting green construction. *USGA Journal and Turf Management* 13(5):24-28. (TGIF Record 18443)

17. Walker, J., and S.-K. Chong. 1986. Characterization of compacted soil using sorptivity measurements. *Soil Sci. Soc. Am. J.* 50:288-291.