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Water Flow Through Sand-based Root Zones Atop Geotextiles

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***Abstract*. An alternative to the time-tested gravel drainage layer beneath a sand-based root zone of a sports field or golf putting green can be constructed from a geotextile atop a highly porous drainage material or structure. The geotextile serves to support the root zone mixture on the drainage layer whose pores can be too large for the sand to support itself by bridging. In such an application, the geotextile should have high enough strength and resistance to stretching to support the root zone mixture atop the pores of the drainage layer and should contain internal pores of appropriate size to retain the bulk of particles in the root zone mixture and to allow free passage of drainage water and eluviating fine particles. The objective of this study was to determine whether geotextiles selected to meet these criteria affect the drainage rates of sand-based root zones and whether they affect the size of particles lost from the root zone–geotextile systems. In a 1-year laboratory study that made use of 150-mm diameter polyvinyl chloride (PVC) test cells, measurements of drainage rates and saturated hydraulic conductivities were made on replicated combinations of 10 geotextiles and three 300-mm deep root zone mixtures. Size distributions and total masses of particles that passed from the root zones through the geotextiles were measured. Statistical analyses showed that drainage rate, saturated hydraulic conductivity, and size distribution and mass of eluviated particles were unaffected by the properties of the geotextiles. The results gave of no reason to prohibit the use of geotextiles to support sand-based root zones in golf putting greens or sports fields.**

Golf putting greens and sports fields that are designed to use a geotextile to retain a sand-based root zone mixture atop a drainage layer are an alternative to the popular design recommended by the U.S. Golf Association (USGA) where the root zone mixture is placed directly atop gravel (USGA Green Section Staff, 2004). The geotextile-based design allows use of drainage layer materials with pores that are too large for the root zone mixture to support itself atop by self-bridging the drainage layer voids as happens when a USGA-recommended (USGA Green Section Staff, 2004) root zone mixture is placed atop gravel with a USGA-recommended particle size distribution. In this respect, the geotextile-based design puts less restriction on the particle size distribution of gravel that can be used and it allows the use of synthetic drainage structures designed to transmit more water per unit depth than does gravel. Although use of geotextiles offers this and other advantages (McInnes and Thomas, 2011), there has not been widespread acceptance, in part because of the possibility that geotextile pores, generally being smaller than that of gravel, could clog with particles eluviating the root zone and consequently restrict drainage and lead to poor performance or failure of the putting green or sports field. This nagging concern continues although extensive research has been conducted on appropriate choices of geotextiles to minimize clogging when they are used to retain soil for engineering purposes (e.g., Koerner, 1998; Koerner et al., 1993; Mlynarek et al., 1991) and the research of Callahan et al. (1997a) more than a decade ago that demonstrated long-term successful use of geotextiles to retain a turfgrass root zone above gravel.

Numerous commercially available geotextiles have sufficient strength and resistance to stretching necessary to support a sand-based root zone atop large pores in a drainage structure, even pores that exceed 50 mm width such as those found in AirDrain (a 25-mm deep highly porous polypropylene geogrid; AirField Systems, Oklahoma City, OK), so choice of a geotextile in a putting green or sports field would be based on cost of the textile and on its ability to transmit drainage water along with particles eluviating from the root zone. Pore sizes of geotextiles are commonly reported by the manufacturer as apparent opening size (AOS), the diameter where 95% of the pores in the geotextile are smaller (ASTM, 2004a; Sarsby, 2007). Apparent opening size essentially gives an estimate of the size of the largest particle that can pass through the geotextile. Clay, silt, and very fine sand are known to migrate in sand-based root zone mixtures (Callahan et al., 1997b; Whitmyer and Blake, 1989; Wright and Foss, 1968). Limiting the available geotextiles to those with AOS larger than very fine sand (150 μm or greater) still leaves plenty whose reported permeability is high enough not to initially limit flow of water from a root zone with USGA-recommended hydraulic properties. The purpose of this study was to evaluate the hydraulic and particle-sieving effects of such geotextiles in various sand root zone–geotextile combinations.

Materials and Methods

Test cells were prepared to hold 25 mm of air space above 300 mm of sand-based root zone mixture placed atop a geotextile overlying a geogrid that allowed free lateral drainage. The cells consisted of 153-mm inner

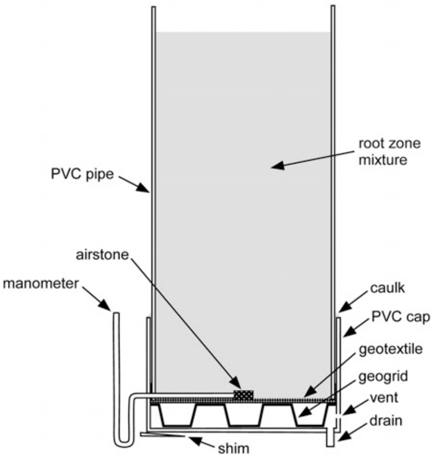

Fig. 1. Schematic diagram of a longitudinal cut of a test cell used to hold a root zone mixture above a geotextile.

Table 1. Manufacturers' reported properties of the geotextiles used in the study.

Geotextile	Manufacturer	Type[z]	Material[y]	AOS[x] (mm)	Flow rate[w] (mm·s^{-1})
NW10	GSE	N	PP	0.150	51
NW16	GSE	N	PP	0.150	31
GEOTEX 401	Propex	N	PP	0.212	95
GEOTEX 1001	Propex	N	PP	0.150	58
GEOTEX 351	Propex	N	PP	0.300	102
GEOTEX 104F	Propex	W	PP	0.212	12
FW404	TenCate	W	PP	0.425	48
TYPAR 3301	Fiberweb	S	PP	0.300	65
TYPAR 3341	Fiberweb	S	PP	0.250	58
Lutradur 097	Freudenberg	S	P	0.198	157

[z] N = needlepunch; W = woven; S = spunbond.
[y] PP = polypropylene; P = polyester.
[x] Apparent opening size (ASTM, 2004a).
[w] Water flow rate at 50 mm head pressure (ASTM, 2004b).

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diameter × 350-mm long sections of PVC pipe, flat-bottom PVC end caps with drainage holes on one side of the bottom, an assortment of geotextiles, 159-mm diameter disks made from AirDrain (AirField Systems), tube fittings, and tubing (Fig. 1). To construct a cell from these components, a 200-mm diameter disk of one of the geotextiles was centered over an end cap that contained a drainage space disk in the bottom and then a section of pipe was driven into the cap until the geotextile came in contact with the disk. With the thicker geotextiles, the cap was cut to a slightly larger inner diameter to make room for the fabric between the pipe and cap. The top of the cap was sealed to the pipe with silicone caulk. To facilitate drainage out of the hole in the bottom of the cap, a vent hole was drilled on the side of the cap midway between the bottom and the geotextile. An aquarium airstone connected to clear flexible tubing was placed at the interface of the root zone mixture and the geotextile in each test cell. The tubing exited the test cell through a hole that was level with the airstone. After exiting a test cell, the tube formed a U-shaped manometer with the bottom of the U level with the base of the PVC cap (Fig. 1). The manometers connected to the airstones were used to determine if the geotextiles restricted water flow out of the test cells as would be evidenced by positive pressure in the water at the root zone–geotextile interface during drainage. They also served as tensiometers for a very limited range (0 to 20 mm) of water tensions. The airstones served two purposes; they prevented sand from migrating into the tubing and they prevented air from entering the tubing when the root zone water was under limited tension.

Ten geotextiles with suitable strength and AOS 150 μm or greater were investigated (Table 1). Three root zone mixtures were combined with the 10 geotextiles and replicated three times for a total of 90 test cells. The three root zone mixtures with varying amounts of fines (Table 2) were made from a silica sand (US Silica Company, Kosse, TX) that met the USGA recommendation for particle size distribution, a sandy clay loam soil collected near College Station, TX, and a non-calcareous sand (Living Earth, Houston, TX) with fines (particles less than 150 μm diameter) in excess of the USGA recommendation. Mixture 1 was the sand that met the USGA recommendation, Mixture 2 was a 9:1 blend (by mass) of the sand in Mixture 1 and a sandy clay loam soil, and Mixture 3 was a 1:1 blend (by mass) of the sand in Mixture 1 and the sand with excess fines. Mixtures 2 and 3 were blended in a cement mixer before use. Saturated hydraulic conductivities, K_{sat}, measured on 76-mm diameter cores (ASTM, 2006) were 120, 58, and 53 $\mu m \cdot s^{-1}$ for Mixtures 1 to 3, respectively, all greater than 42 $\mu m \cdot s^{-1}$ (greater than 6 $in \cdot h^{-1}$) as recommended by the USGA. The relationship between water content and water tension of the root zone mixtures (Fig. 2) was measured by gravimetrically determining the water contents of 50-mm vertical sections of 300-mm tall × 76-mm diameter columns of the root zone mixtures that had been irrigated with an amount of water equivalent to three pore volumes of the root zone mixtures and then allowed to drain for 24 h while being covered to minimize evaporation.

To determine the amounts of root zone mixtures to add to test columns, 0.7-kg samples of each mixture were made to a gravimetric water content of 0.05 $kg \cdot kg^{-1}$ and then compacted in a 76-mm diameter PVC cylinder using a drop-hammer with the appropriate mass and height of drop to meet the USGA recommendations (USGA Green Section Staff, 2004). The dry bulk density was determined from the wet bulk density and the gravimetric water content. Each mixture was tested in triplicate and the average bulk densities were 1.63 $Mg \cdot m^{-3}$ for Mixtures 1 and 2 and 1.65 $Mg \cdot m^{-3}$ for Mixture 3. The appropriate amounts of each root zone mixture were then packed into pre-assembled test cells. The root

Table 2. Particle size distribution for the three root zone mixtures used in the study along with the USGA recommendations for sand used in a putting green mixture.

Classification	Diam (mm)	Mixture 1	Mixture 2	Mixture 3	USGA recommendation[z]
		$(g \cdot kg^{-1})$			
Fine gravel	2.0 to 3.4	0	0	0	<30
Very coarse sand	1.0 to 2.0	85	75	51	<100, including fine gravel
Coarse sand	0.5 to 1.0	427	381	257	>600, coarse plus medium sand
Medium sand	0.25 to 0.50	342	322	339	
Fine sand	0.15 to 0.25	112	125	216	<200
Very fine sand	0.05 to 0.15	17	36	110	<50
Silt plus clay	<0.05	17	61	27	<50 silt, <30 clay
Total fines	<0.15	34	97	137	<100

[z] USGA Green Section Staff (2004).

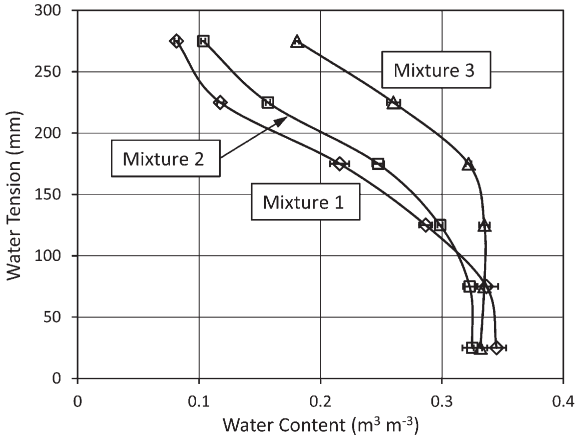

Fig. 2. Relationships between water content and water tension for the three root zone mixtures used in the study. Each data point represents the mean value of three replicates and the error bars represent the mean ± SE.

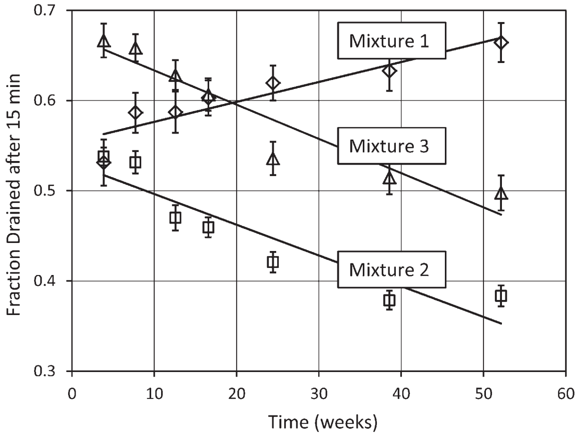

Fig. 3. Fraction of applied water drained from test cells 15 min after irrigation over the course of the yearlong study. Each data point represents the mean value of readings from 30 test cells having a common root zone mixture (i.e., an average across 10 geotextile treatments with three replicates) and the error bars represent the mean ± SE.

zone mixtures were added in three lifts to produce a total depth of 300 mm. To reduce layering effects, the top of the mixtures in the cells from the first and second lifts were scarified before adding the next layer. The test cells were moved to a laboratory and placed on plywood benches that allowed electronic balances holding 1-L plastic containers to collect the drainage water to be placed underneath. The cells were canted slightly with a shim to facilitate lateral movement of water and eluviated particles toward the drainage hole and out of the caps on the bottoms of the cells.

Synthetic rainwater manufactured according to the composition reported by Laegdsmand et al. (1999) was used for irrigation water throughout the study. To bring the test cells to water-holding capacity and initiate drainage, the cells were irrigated with 76.2 mm depth of water (applied by hand in 6.4-mm depth aliquots every 15 min). To simulate watering during the establishment of turfgrass cover, for the first 2 weeks, the cells were irrigated daily with 19 mm of water. This amount was halved every 2 weeks until the amount was 4.8 mm, where it remained for the duration of the study. Drainage rate data were collected on the second of two applications of 25-mm depth of water separated by 1 d. After the first application, the cells were covered and allowed to drain overnight. Before the second application, the manometers were primed with water. After the second application, the cumulative masses of water drained from the cells were recorded every 5 s for the first hour then again at 24 h using electronic balances (Model SP2001; Ohaus, Pine Brook, NJ) connected to a laptop computer. Masses of water drained were corrected for evaporation. Six balances were used to record drainage rates so measurements from the 90 cells were staggered in time. The levels of the water in the manometers were recorded over the course of the first hour after application of water. Measurements of drainage rate and observations of the manometer were made at 27, 54, 88, 116, 171, 270, and 365 d after the start of the study.

Table 3. Analysis of variance of the temporal rate of change in the fraction of water drained from the root zone mixtures 15 and 60 min after application of 25 mm water and the significance of coefficients of linear models of the temporal rate of change as a function of apparent opening size and flow rate of the geotextiles.

	15 min	60 min
Source of variation	$P > F$	$P > F$
Mixture	< 0.001	0.021
Geotextile	0.964	0.720
Replicate	0.002	0.175
Mixture:geotextile	0.936	0.812
Coefficients (linear model)	$P > \lvert t \rvert$	$P > \lvert t \rvert$
Intercept	0.170	0.522
Apparent opening size	0.657	0.842
Flow rate	0.826	0.850

The particles eluviated from the root zone mixture and collected in the drainage water from each cell were flocculated with sodium chloride. After flocculation, the supernatant salt solution was decanted and the particles were accumulated for six months. After that time, the salt in the accumulated particles was removed using dialysis tubing (Spectra/Por® 4; Spectrum Laboratories, Rancho Dominguez, CA). The dialyzed particles were then mixed with dilute sodium metaphosphate solution and dispersed using a magnetic stirrer. While being suspended with the stirrer, a subsample of the particles was removed by pipette and dispensed into a laser particle size analyzer (Model LS230; Beckman Coulter, Inc., Brea, CA) where the particle size distribution was measured. Values of d90 (diameter in which 90% of the particles are finer) were determined from the particle size distributions. The remaining particles were dried at 105 °C and weighed to determine a total mass of particles lost from a cell through eluviation.

One year after the start of the experiment, the saturated hydraulic conductivities of the treatments in all test cells were determined after developing constant heads of 10 mm water at the surfaces of the mixtures in the cells and recording steady-state rates of water discharge from the bottoms.

The effects of the geotextiles and root zone mixtures on drainage rates, cumulative masses, and size distributions of particles passing through the geotextiles and K_{sat} were assessed with the analysis of variance (*aov*), linear models (*lm*), and Tukey honestly significant difference (*TukeyHSD*) statistical functions in R (R Development Core Team, 2009).

Results

Drainage rates. Because evaporation was minimized during the measurements of drainage from the test cells, the amounts of water drained from the columns after 24 h were always found to be very close to the 25 mm applied. Statistical analysis of that data is not reported because differences between treatments were small and not statistically significant. The amount drained after 15 and 60 min varied with treatments and time over the yearlong study (Fig. 3) being influenced by a combination of the degrees of saturation and the hydraulic conductivities of the root zone mixtures in the cells. Mixture 1 had over twice the K_{sat} as Mixture 3 at the start of the study, but for the first few months, less water drained after 15 min from cells containing Mixture 1 than Mixture 3. The reason for this early difference in drainage lies in the fact that Mixture 3 remained nearer saturation and took less water to saturate the profile than Mixture 1. From the water retention data (Fig. 2), 34, 25, and 11 mm were required to saturate the profiles of Mixtures 1, 2, and 3, respectively. Given these differences, over half of the water applied to the cells with Mixture 3 was conducted through saturated flow, whereas water applied to cells with Mixture 1 never fully saturated the profile. Temporal drainage rate from any cell with Mixture 3 showed a short-term linear phase when drainage was governed by the K_{sat}. There were no distinct linear phases in drainage from the cells with Mixtures 1 or 2. Unsaturated hydraulic conductivity of sand decreases rapidly with decreasing water content (Campbell, 1974) so the influence of the difference in K_{sat} on drainage was offset by the decrease in conductivity at partial saturation. For statistical analyses, we chose to test the effects of the root zone mixture and geotextile treatments on the long-term temporal rate of change in the fraction of water drained from the root zones mixtures rather than the specific amounts of water drained because the former is indicative of clogging within the mixtures as a result of illuviation of fine particles or of clogging of the geotextile resulting from sieving of fine particles that eluviated the mixtures. The long-term temporal rate of change was determined as the slope of a linear regression of fraction of water drained with time from the beginning of the study. Values of K_{sat} for the root zone mixture–geotextile combinations were measured separately and the statistics for the effects of the treatments are reported later.

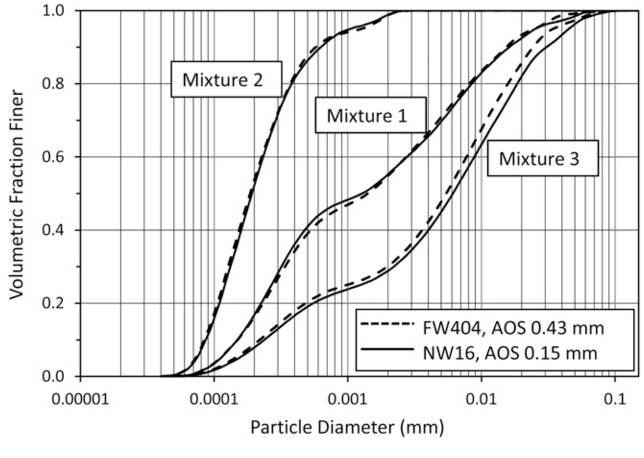

Fig. 4. Fraction of eluviated particles finer than a given diameter. Data from test cells with geotextiles having the largest difference in apparent opening size (AOS) are shown. Data lines represent average curves of three replicates.

The long-term rates of change in the fractions of water drained after 15 or 60 min were unaffected by the geotextiles, but they were affected by the root zone mixtures (Table 3). There was no interactive effect of root zone mixture with geotextile on the rates of change. The rates of change were not correlated with the magnitudes of AOS or flow rate of the geotextiles (Table 3). Water levels recorded in the manometers never indicated any positive pressures at the interfaces between the root zone mixtures and geotextiles, indicating that the geotextiles were not limiting flow.

Table 4. Analysis of variance of the total mass and d90 particle size of the particles eluviated from the root zone through the geotextiles over the first six months of the study and significance of coefficients of linear models of total mass and d90 particle size of the particles as a function of apparent opening size and flow rate of the geotextiles.

	Mass	d90
Source of variation	*P* > F	*P* > F
Mixture	<0.001	< 0.001
Geotextile	1	0.602
Replicate	<0.001	0.045
Mixture:geotextile	1	0.758
Coefficients (linear model)	*P* > |t|	*P* > |t|
Intercept	0.070	0.018
Apparent opening size	0.959	0.403
Flow rate	0.964	0.777

Table 5. Analysis of variance of saturated hydraulic conductivity, K_s, after one year from the start of the study, and significance of coefficients of a linear model of K_s as a function of apparent opening size (AOS) and flow rate of the geotextiles.

Source of variation	*P* > F
Mixture	<0.001
Geotextile	0.657
Replicate	0.080
Mixture*geotextile	0.969
Coefficients (linear model)	*P* > |t|
Intercept	0.001
AOS	0.664
Flow rate	0.704

Eluviated fines. The size distributions of particles that passed out of the root zone mixtures and through the geotextiles did not appreciably vary between cells with different geotextiles. This observation is highlighted in the size distributions of particles passing the cells having the geotextiles with the smallest and largest AOS (Fig. 4). The total masses and d90 sizes of particles collected in the drainage waters were affected by the root zone mixtures but not by the geotextiles (Table 4). There was no interactive effect of root zone mixture with geotextile on the total masses or d90 sizes. The majority of particles passing out of the cells with Mixtures 1 and 3 were from the silt and clay fractions (Fig. 4), and the total masses accounted for 2.7% and 0.3% of the amounts of silt and clay initially in the cells with those two mixtures, respectively. The majority of particles passing out of cells with Mixture 2 were clay-sized and the total amount lost accounted for 7.6% of the clay that was originally in the cells with this mixture. Regression analysis showed that neither total mass nor d90 of particles were correlated with the magnitudes of AOS or flow rate of the geotextiles (Table 4).

Saturated hydraulic conductivity. After one year in the test cells, the average K_{sat} of the root zone mixture–geotextile combinations were 120, 83, and 19 $\mu m \cdot s^{-1}$ for test cells containing Mixtures 1, 2, and 3, respectively. The average K_{sat} of the Mixture 1–geotextile combinations was the same as the K_{sat} measured in separate columns before the study, the average K_{sat} of the Mixture 2–geotextile combinations was greater than that measured before the study, and the average K_{sat} of the Mixture 3–geotextile combinations was less than that measured before the study. Because an appreciable amount of clay was lost from cells containing Mixture 2–geotextile combinations, it was likely that the increase in K_{sat} was a consequence of the opening of flow channels with the eluviation of clay from the mixture. The K_{sat} of the Mixture 3–geotextile combinations declined to a level below the minimum recommended by the USGA Green Section Staff (2004). There was little silt and clay lost from the cells having Mixture 3 so the decline in K_{sat} was likely from internal clogging of pores with the illuviation of fines because there were no positive pressures recorded at the root zone mixture–geotextile interfaces.

Analysis of variance in the K_{sat} data showed that the root zone mixtures influenced the permeabilities of the root zone mixtures–geotextile combinations in the test cells and that the geotextiles had not influenced the permeabilities (Table 5). There was no interactive effect of root zone mixture with geotextile on permeability. Regression analysis showed that K_{sat} was not correlated with either the magnitude of AOS or flow rate of the geotextile (Table 5). We observed that two of the cells that contained Mixture 3 showed appreciably lower conductivity than the other two replicates having the same geotextile. To investigate if the decline in the permeability of the root zone mixtures in these columns was the result of clogging of pores within the mixtures, we tested the variation of K_{sat} with depth in the cells. When 50-mm incremental layers from the cells were removed, the K_{sat} of the remaining materials in the cells increased appreciably (Fig. 5) suggesting that the observed decline in permeabilities was the result of clogging within the root zone mixtures and not of the geotextiles.

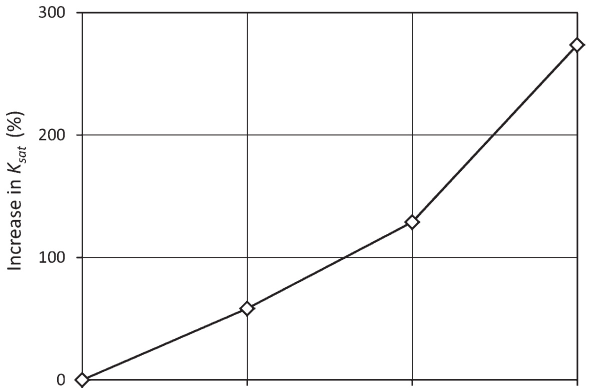

Fig. 5. Saturated hydraulic conductivity of root zone mixture remaining in a test cell after incremental removal of 50-mm layers of the root zone mixture from the surface. Data were collected one year after initiation of the study from Replicate 1 of the test cell containing Mixture 3 and Geotextile 3301L.

Conclusion

Our data support the findings of Callahan et al. (1997a, 1997b) that geotextiles can be used to support a sand-based root zone atop porous drainage structures such as AirDrain and presumably gravel that is coarser than that currently recommended for USGA-design putting greens. This conclusion is based on our findings from laboratory-based test cells that geotextiles did not have an effect on any of the following: short-term drainage rate, saturated hydraulic conductivity, pore water pressure at the root zone–geotextile interface, and size of particles in drainage water.

Literature Cited

ASTM. 2004a. Standard test method for determining Apparent Opening Size of a geotextile. D4751-04. ASTM International, West Conshohocken, PA.

ASTM. 2004b. Standard test methods for water permeability of geotextiles by permittivity. D4491-99a. ASTM International, West Conshohocken, PA.

ASTM. 2006. Standard test methods for saturated hydraulic conductivity, water retention, porosity, and bulk density of putting green and sports turf root zones. F1815-06. ASTM International, West Conshohocken, PA.

Callahan, L.M., R.S. Freeland, R.D. von Bermuth, D.P. Shepard, J.M. Parham, and J.M. Garrison. 1997a. Geotextiles as substitutes for choke layer sand in USGA greens. I. Water infiltration rates and water retention. International Turfgrass Society Research Journal 8:65–74.

Callahan, L.M., R.S. Freeland, R.D. von Bermuth, D.P. Shepard, J.M. Parham, and J.M. Garrison. 1997b. Geotextiles as substitutes for choke layer sand in USGA greens. II. Particle migration and condition of separation layers. International Turfgrass Society Research Journal 8:75–86.

Campbell, G.S. 1974. A simple method for determining unsaturated conductivity from moisture retention data. Soil Sci. 117:311–314.

Koerner, R. 1998. Designing with geosynthetics. 4th Ed. Prentice Hall, Englewood Cliffs, NJ.

Koerner, R.M., Y. Hsuan, and A.E. Lord. 1993. Remaining technical barriers to obtaining general acceptance of geosynthetics. Geotextiles Geomembranes 12:1–52.

Laegdsmand, M., K.G. Villholth, M. Ullum, and K.H. Jensen. 1999. Processes of colloid mobilization and transport in macroporous soil monoliths. Geoderma 93:33–59.

McInnes, K.J. and J.C. Thomas. 2011. Water storage in putting greens constructed with United States Golf Association and Airfield Systems designs. Crop Sci. 51:1261–1267.

Mlynarek, J., J.B. Lewandowski, A.L. Rollin, and G. Bolduc. 1991. Soil geotextile system interaction. Geotextiles Geomembranes 10:161–176.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Sarsby, R.W. (ed.). 2007. Geosynthetics in civil engineering. Woodhead Publishing, Cambridge, UK.

USGA Green Section Staff. 2004. USGA recommendations for a method of putting green construction. USGA Green Section Record 31:1–3.

Whitmyer, R.W. and G.R. Blake. 1989. Influence of silt and clay on the physical performance of sand–soil mixtures. Agron. J. 81:5–12.

Wright, W.R. and J.E. Foss. 1968. Movement of silt-sized particles in sand columns. Soil Sci. Soc. Amer. Pro. 32:446–448.