Water Storage in Putting Greens Constructed with USGA and Airfield Systems Designs

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OVERVIEW

The standard USGA design for a putting green uses 4 in (100 mm) of gravel to support the root zone and allow for lateral drainage of excess water to drain lines. The Airfield Systems' (Edmond, OK) design for a putting green uses a geotextile atop a1-in (25 mm) deep plastic geocell structure (AirDrain) to support the root zone and allow for drainage. The rationale for the research reported here was anecdotal information from sports field managers that fields constructed with the Airfield Systems' design held more water in the root zone profile than did fields constructed with the standard USGA design. We believed the reason for these differences in water holding capacity would be found in the differences in tensions that developed at the bottom of the root zones in the two designs. This research report is composed of three sections. Each section summarizes an experiment or a set of experiments conducted to understand a certain aspect of water flow and retention in an Airfield Systems' designed green. In the first two sections of this report, water flow and retention in Airfield Systems' designed putting greens are compared to the similar flow and retention in standard USGA designed greens. In the third section, comparisons are made between water flow rates through test greens constructed using different geotextiles in Airfield Systems' design. The research is a collaborative effort between Texas A&M University (College Station), Airfield Systems (Edmond, OK), and the USGA.

MAJOR FINDINGS

- With the same root zone mixture, a putting green constructed with Airfield Systems' design holds appreciably more water than a putting green constructed according to the standard USGA design. If the procedure for testing a root zone mixture to determine whether it meets USGA recommendations were to be used to test a mixture for an Airfield Systems' design putting green, the tension at which the air-filled porosity and capillary porosity were determined should be lowered by 50 mm water.

- It is feasible to prevent droughty areas from appearing on the upper portion of putting green slopes by installing impermeable subsurface barriers, at the bottom of the root zone and perpendicular to the slope, to restrict downslope movement of water.

- Particle size distribution of the root-zone mixtures affects drainage rate in an Airfield Systems' designed putting green, as expected, but apparently much more through clogging of pores within the root zone itself rather than through clogging of pores in the geotextile.

SECTION 1

WATER STORAGE IN PUTTING GREENS CONSTRUCTED WITH USGA AND AIRFIELD SYSTEMS DESIGNS

INTRODUCTION

The quantity and distribution of water stored in the root zone of a golf course putting green after irrigation or rainfall are important characteristics that govern the ability to sustain a healthy turfgrass. The United States Golf Association has developed a set of recommendations for the desired physical properties and depth of sand-based root zone mixtures to be used in putting greens (USGA Green Section Staff, 2004). Putting greens constructed according to these recommendations have 300 mm of an acceptable root zone mixture placed over a 100-mm thick gravel drainage layer that blankets a compacted soil base (USGA Green Section Staff. 2004). An alternative to this USGA design is the Airfield Systems design that replaces the gravel with a geotextile atop a 25-mm deep highly porous plastic drainage structure (AirDrain geocell, Airfield Systems, Oklahoma City, OK) over a PVC liner covering a compacted base. While both gravel and the AirDrain geogrid allow rapid lateral movement of excess water to drain lines, there is anecdotal evidence from sports field managers that the two types of drainage structures produce different degrees of water retention in the root zones. To utilize the widely accepted USGA recommendations for physical properties of root zone mixtures in designing a putting green using geotextile/AirDrain (geotextile atop AirDrain) instead of gravel, it was of interest to know if and why differences in water retention exist between the two methods of putting green construction.

With knowledge of the vertical distribution of volumetric water content in the root zone of a putting green, the total amount of water stored in the profile can be determined. This stored water is under tension and the water content and water tension are related so the total amount of water stored after drainage has ceased also can be determined from knowledge of the vertical distribution of water tension within the profile. Since the matric and gravitational potentials of the root zone water are in equilibrium after drainage, the total water stored in the profile *D* [mm] can be calculated as

$$D = \int_{h_b}^{h_b + z_{rz}} \theta(h) \cdot dh \qquad [1]$$

where h is water tension, $\theta(h)$ is a function giving the relationship between volumetric water content and water tension, h_b is the water tension at the bottom of the root zone profile, and z_{rz} is the depth of the root zone. Because of the shapes of the $\theta(h)$ relationships for root zone mixtures commonly used in construction of putting greens, D decreases as h_b increases. For 300-mm deep root zones that meet the USGA recommendations for particle size and water retention (USGA Green Section Staff, 2004), the rate of decrease in D is a near-linear function of h_b for $0<h_b<100$ mm, usually between 0.2 and 0.3 $m \cdot m^{-1}$. From the differences in depths of the two drainage structures and the decrease in D with tension, it would be expected that if a difference in h_b between the two methods of construction were to exist, that difference would be <100 mm water, and that the difference in water stored in the root zones would be <30 mm water (<100mm·0.3 $m \cdot m^{-1}$).

The purpose of the study reported in this first section was to evaluate the amount of water stored in root zones of golf course putting greens constructed with sand-based root zone mixtures placed above geotextile/AirDrain or gravel drainage systems.

EXPERIMENTAL DESIGN

The experimental units (hereafter referred to as test greens) were constructed from 332-mm ID PVC pipe fixed to a 20-mm thick plywood base with 1-mm thick PVC liner separating the two components. A small notch was cut on one side of the bottom of the PVC pipe to allow drainage water to escape. The test greens contained either gravel or geotextile/AirDrain drainage systems. With gravel drainage, the test green columns were 430-mm tall and contained 300 mm root zone mixture atop 100 mm gravel. With geotextile/AirDrain drainage, the test green columns were 355-mm tall and contained 300 mm root zone mixture atop a 25-mm tall geotextile/AirDrain structure.

For the root zone mixtures, three sands were chosen such that their particle-size distributions spanned the range found within the USGA recommended limits (USGA Green Section Staff, 2004). Caylor White sand (Caylor Sports Sands, Hewitt, Texas), Sure Play sand (US Silica, Kosse, Texas), and Texas Coarse Special sand (US Silica, Kosse, Texas) had particle-size distributions that fell toward the fine side, middle, and coarse side of the USGA recommendation, respectively (Fig. 1). Except for Caylor White sand having too much fine sand (150 to 250 μm diameter); the three sands met the USGA recommendation for particle-size distribution. Three gravels also were chosen such that their particle-size distributions, as determined by sieving, fell toward the fine side, middle, and coarse side of the USGA recommendation (Fig. 1). All three gravels met USGA recommendations for particle-size distribution (USGA Green Section Staff, 2004). Silt plus clay content of all the sands and gravels were <5 g/kg (<0.5%).

For the sands, reference diameters d_{15} (the diameter where 15% of the particles by mass are smaller) and d_{85} were determined from the fraction finer data using the model of Fredlund et al. (2000) to interpolate between data points. For the gravels, d_{15} and d_{90} were determined from the fraction finer data with cubic-spline interpolation. Using these reference diameters for the sands and gravels, all possible sand-gravel combinations were evaluated for compatibility with the USGA recommendation (USGA Green Section Staff, 2004). Except for the Caylor White sand not meeting the bridging factor when combined with the coarsest gravel, the sands met the USGA-recommended criteria for use with the gravels without an intermediate (choker) layer of sand. To create root zone mixtures, the Sure Play and Texas Coarse Special sands were amended with 10% and 20% screened sphagnum peat moss by volume, respectively. Caylor White sand was used without amendment. Saturated hydraulic conductivity of the root zone mixtures were determined following standard procedures (ASTM, 2006). With the absence of appreciable silt and clay, the saturated conductivities of all three root zone mixtures were >1.3 $m \cdot h^{-1}$ (>50 $in \cdot h^{-1}$), which is considerably greater than the USGA recommended minimum of 150 $mm \cdot h^{-1}$ (6 $in \cdot h^{-1}$).

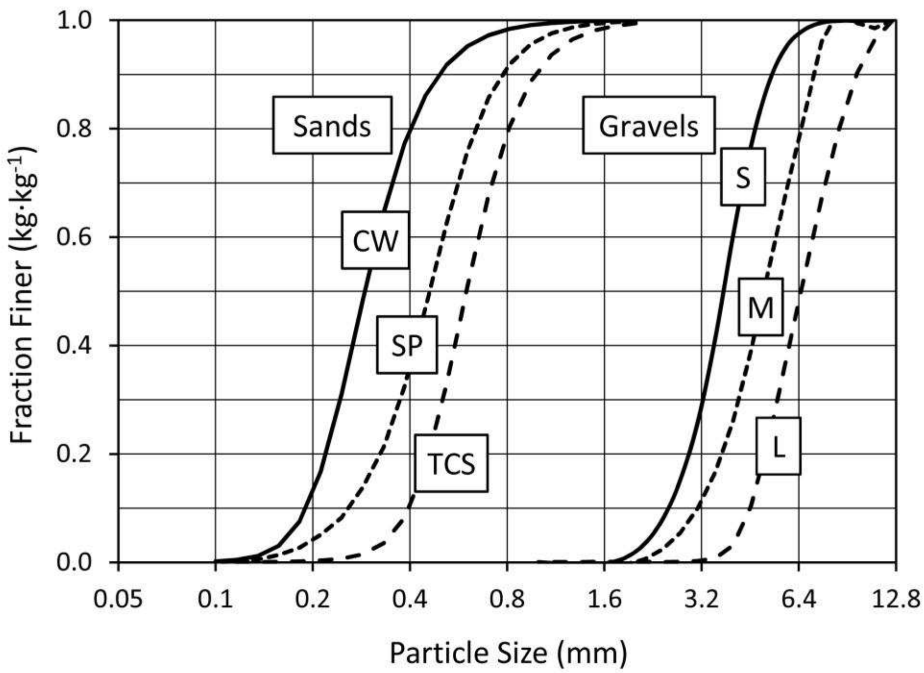

Figure 1. Particle-size distributions of the sands in the root zone mixtures and of the gravels used in the study. Root zone mixtures: Caylor White (CW), Sure Play (SP), Texas Coarse Special (TCS). Gravels: Large (L), Medium (M), Small (S).

The relationship between water content and water tension for a given root zone mixture (Fig. 2) was determined in columns created by first packing (ASTM, 2006) the root zone mixture into 75-mm ID by 50-mm tall segments of PVC pipe and then stacking segments on top of each other to a total height of 450 mm. An additional empty segment was placed at the top of each stack to hold water, and the seams between the segments were then sealed with tape. Three replicate columns were created for each root zone mixture. The resultant columns were watered from the top until water drained from the bottoms and then covered with plastic bags to minimize evaporation and allowed to drain for 24 h. The columns were rewetted and allowed to drain for 24 h two more times before they were disassembled to determine gravimetric water content of the root zone mixture in each of the segments. Volumetric water content was determined from the mass of water lost on oven drying at 105 °C, the density of water, and the internal volume of the segment. In generating the data to determine the relationships between water content and water tension, we desired a realistic field level of saturation, with entrapped air. No attempt was made to fully saturate the root zone mixtures in the columns before draining so there was noticeably less water in the bottom segments than would be estimated from saturation of the total porosity. The degree of saturation obtained at the bottom of the columns was about 85% for all root zone mixtures. The relationship between water content and water tension for each root zone mixture was characterized with the model of Van Genutchten (1980) using the mean volumetric water content of three replicates. Using the Van Genutchten equation to represent $\theta(h)$, D was determined as a function of h_b for each root zone mixture (Eq. 1). The slopes of these D vs. h_b

relationships for Caylor White, Sure Play, and Texas Coarse Special root zone mixtures were 0.26, 0.23, 0.21 m·m^{-1}, respectively.

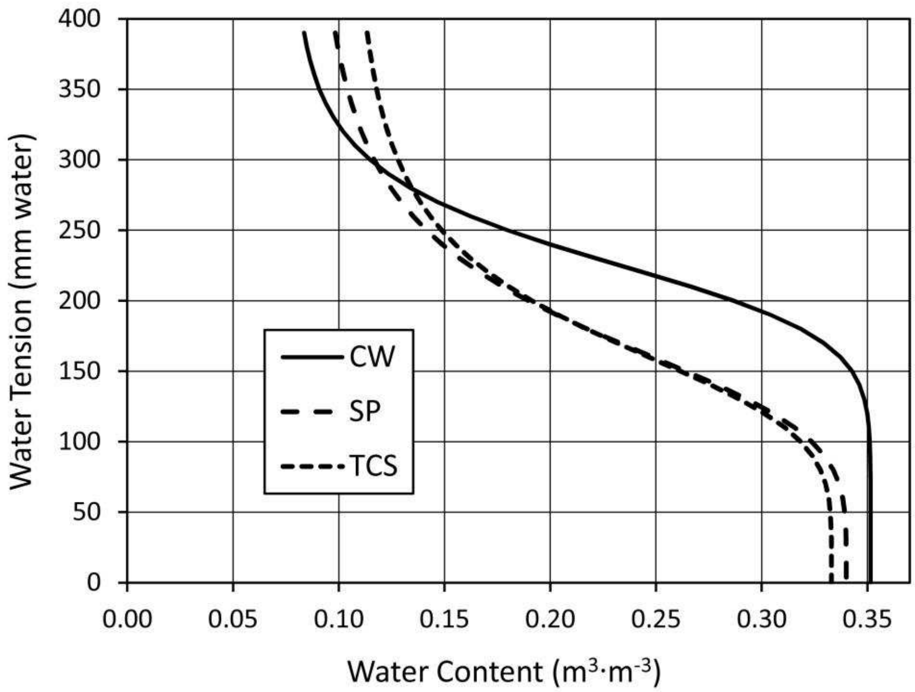

Figure 2. Relationships between volumetric water content and water tension for the three root zone mixtures used in the studies. Sure Play and Texas Coarse Special had 10% and 20% sphagnum peat moss added by volume, respectively.

Four geotextiles having apparent opening sizes AOS (ASTM, 2004) near 200 μm, but that represented different chemical compositions and manufacturing processes, were chosen to support the root zone mixtures atop AirDrain in the test greens (Table 1). One of the geotextiles was a woven fabric. One of the nonwoven geotextiles was a needlepunch type material (produced from mechanically entangled staple fibers), the other two were spunbond type materials (produced from thermally or chemically bonded randomly laid continuous filaments). The permeabilities of all four geotextiles were high enough that they would not have been expected to limit drainage of water from the root zone mixtures placed atop them.

Table 1. Geotextiles used to retain the root zone mixtures atop the AirDrain drainage structure.

Supplier	Product	Type	Composition	AOS† (μm)	Flow Rate‡ (mm/s)
Propex	Geotex 401	needle punch	polypropylene	212	95
Propex	Geotex 104F	woven	polypropylene	212	12
Fiberweb	Typar 3401	spunbond	polypropylene	212	41
Freudenberg	Lutradur 097, 130g	spunbond	polyester	198	157

† ASTM (2004), value reported by the manufacturer
‡ ASTM (2009), value reported by the manufacturer

Each of the root zone mixture treatments was combined with each of the gravel and geotextile treatments, and the test greens containing each combined treatments were replicated three times. For the test greens containing gravel, the gravel was added to the bottom of column and tamped. Gravel was added or removed and retamped until its depth was uniformly 100 mm across the bottom of the test green column. For the test greens containing geotextile/AirDrain, a disk of AirDrain was cut from stock and placed on the PVC liner covering the plywood in the bottom of the test green column. A ring of silicone caulk was then placed on the inside of the column just above the AirDrain followed by a disk of a geotextile about 40 mm larger diameter than the ID of the column that sat on top of the AirDrain. The outer edge of the oversized disk of geotextile was pressed into the silicone caulk and then additional caulk was used to ensure a seal that prevented bypass of water and potentially migrating fines from the root zone mixtures.

Two tensiometer-manometers constructed of aquarium airstones and clear flexible tubing were placed at the interface of the root zone mixture and the drainage material in each test green (Fig. 3). The airstones had an air-entry tension of about 150 mm water. The flexible tubing of each manometer-tensiometer exited the test green through a hole in the column having the diameter of the tubing. The exit holes were located just above the interfaces of the root zone mixtures and the drainage materials. After exiting the test greens, the tubes formed U-shaped manometers with the bottom of the U-loop touching the plywood base. These manometer-tensiometers were used to determine if the geotextiles restricted water flow out of the test greens (as would be evidenced by positive pressure during drainage) and to measure the tensions of the water at the interface of the root zone mixture and the drainage structure (i.e., at the bottom of the 300-mm deep root zone).

Figure 3. Tensiometer-manometers above gravel (left) and geotextile/AirDrain (right) drainage layers at the bottom of the test greens before root zone mixtures were added.

The experimental site was a 4 m by 10 m concrete pad. The plywood bases of the test greens were supported 100 mm above the concrete with lumber treated to prevent decay. Root zone mixtures were packed moist (~8 $g \cdot kg^{-1}$ water content) into the test green columns in ~50 mm lifts to a total depth of 300 mm. The amount of root zone mixture packed in each test green column produced a bulk density equal to that determined by ASTM method F1815-06 (ASTM, 2006). The bulk densities were 1.52, 1.60, and 1.58 $Mg \cdot m^{-3}$ in the Caylor White, Sure Play, and Texas Coarse Special root zones, respectively. The columns were irrigated with water until drainage was observed then sprigged with MiniVerde bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* (Burtt-Davy)] supplied by King Ranch Turfgrass-Wharton Farms, (Wharton, TX). After establishing a solid coverage of turfgrass with typical fertilization and irrigation practices, the dynamics of water content and storage were monitored using a time domain reflectometry (TDR) system (Campbell Scientific, Logan, UT). A 300-mm TDR probe (model CS605) was installed in each test green. The TDR probes were connected through coaxial multiplexers (model SDMX50) to a reflectometer (model TDR 100). The reflectometer was connected to a datalogger (model CR1000) that was programmed to record the apparent length of the TDR probes and temperatures of the root zone every 30 min. Root zone temperatures were monitored with the datalogger using thermocouple thermometers. Volumetric water content of a root zone mixture was determined from the apparent length of the probe through the model of Topp et al. (1980).

To measure the effect of the treatments on the amounts of water stored in the root zone profiles, TDR probes were installed vertically so the probe electrodes ran from top to bottom of the root zone (Fig 4). The test greens were then irrigated until water drained from the bottom, and immediately afterward covered with aluminum foil to minimize loss of water through evapotranspiration. Profile-average volumetric water contents were measured for 48 h and the total amount (depth) of water stored (mm) at any given time was calculated as the product of the profile-average volumetric water content measured by TDR and the depth of the root zone (300 mm). To measure the effect of the treatments on tensions developed at the bottom of the root zones, the manometer-tensiometers were charged with water immediately after irrigation and water tensions were recorded by visual observation for 12 h. To measure the effect of the treatments on the water content that developed in the upper portion of the root zone, TDR probes were installed horizontally through the walls of the test green cylinders at depths centered 75 mm below the turfgrass surfaces. As with the vertical installation, the test greens were irrigated until water drained from the bottom, covered with aluminum foil to minimize evapotranspirative loss

Figure 4. TDR probes installed vertically (left) and horizontally (right) at 3-in (75 mm) depth in the test greens. Vertically installed TDR probes measured average profile water content and horizontally installed probes measure average water content at the depth of installation.

of water, and monitored for water contents for 48 h. Similar studies with vertical or horizontal TDR probes were conducted with test greens left uncovered after watering to observe the temporally dynamics of water storage and water content while water was lost through evapotranspiration.

The effects of Root Zone Mixture (Caylor White, Sure Play, and Texas Coarse Special), Drainage Type (gravel and geotextile/AirDrain), and Drainage Material (large, medium, and small gravels; and Lutradur 097 spunbond, Typar 3401 spunbond, Geotex 401 needlepunch, and Geotex 104F woven geotextiles/AirDrain) were assessed using the *TukeyHSD* and *aov* statistical functions in R (R Development Core Team, 2009).

RESULTS

Water tensions that developed at the root zone-drainage structure interfaces after irrigation increased rapidly over the first hour and after 2 h they reached near maximum values (Fig. 5, left). Tensions immediately after irrigation were appreciably lower than they were at 1 h, but were not recorded. From 1h to 12 h, water tensions at the bottom of the root zones atop any of the three gravels were significantly greater than those at the bottom of the root zones atop any of the geotextile/AirDrain treatments (99% confidence). Averaged across root zone mixtures, water tensions at the bottoms of the root zones 12 h after irrigation were 67 mm and 11 mm water for the test greens with root zones atop gravel and geotextile/AirDrain, respectively. Tensions that developed in the root zones atop the coarsest gravel were significantly less than those developed in the root zones atop the two finer gravels (99% confidence), about 14 mm water less tension. There were no significant differences in the tensions developed at the bottom of the root zones among the four geotextile/AirDrain treatments or between the two finest textured gravel treatments (90% confidence). Test greens with Sure Play root zone mixture atop gravel developed significantly less tension at the bottom of the root zone after 12 h than did test greens with Caylor White root zone mixture atop gravel (95% confidence), about 14 mm water less tension. The reason for this latter difference was not clear. A possible cause was that the Caylor White sand (Caylor White root zone had no peat moss), because of its finer particle sizes and lower ability to bridge voids, had migrated into the gravel and created a capillary wick while the Sure Play root zone mixture had not migrated. This possibility, though, was unlikely the case as the tension at the bottom of both root zones increased from large through medium to small gravel and migration of the Caylor White sand into the gravel would have been more likely to have occurred with the larger (where it did not meet the USGA recommended bridging factor) than the smaller gravel. There were no significant differences in tensions between other combinations of root zone mixture treatments atop gravel or between root zone mixture treatments atop geotextile/AirDrain (90% confidence).

Root Zone Mixture and Drainage Type had significant effects on the amount of water stored in the test greens (Table 2), and as an apparent consequence of the greater tensions that developed at the bottom of the root zones atop gravel compared to those atop geotextile/AirDrain, the amounts of water stored in the root zones of the test greens with gravel drainage were significantly (99% confidence) less than the amounts stored in the root zones atop geotextile/AirDrain drainage. Averaged across root zone mixtures, the difference in the amount of water stored was about 12 mm (Fig. 6). This observed difference in storage was close to that expected using the observed water tensions at the bottom of the root zones and the decreases in stored water with water tension derived from Eq. 1 and the relationships between water tension and water content (Fig. 7). Differences in water content in the upper portion of the root zone between treatments were evident in data collected when the TDR probes were installed horizontally. Averaged across all root zone mixtures, volumetric water content at 75 mm (3 in) depth was 0.033 $m^3 \cdot m^{-3}$ less in test greens with root zone atop gravel than in those with root zone atop geotextiles/AirDrain (Fig. 8). From the relationships between water content and water tension (Fig. 2), and the expected tension 225 mm up from the bottom of the root zones (225+67=292 mm for gravel and 225+11=236 mm for geotextile/AirDrain), the difference in observed water content would have been expected to be slightly larger.

Table 2. Analysis of Variance of the amount of water stored in the root zones of the test greens 12, 24, and 48 h after irrigation. Stored water measured by vertical TDR probes. Water loss was by drainage only.

Source of variation	P(>F) at 12 h	P(>F) at 24 h	P(>F) at 48 h
Root Zone Mixture	<0.001	<0.001	<0.001
Drainage Type	<0.001	<0.001	< 0.001
Root Zone Mixture X Drainage Type	0.39	0.48	0.64

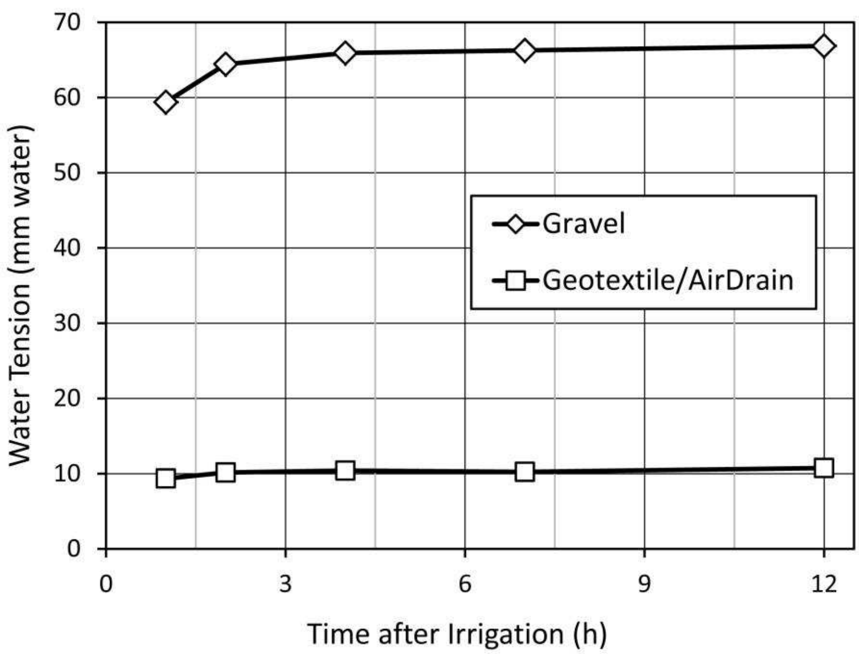

Figure 5. Temporal change in water tension at the bottom of the root zones atop gravel and atop geotextile/AirDrain resulting from drainage of covered test greens. Water loss was by drainage only.

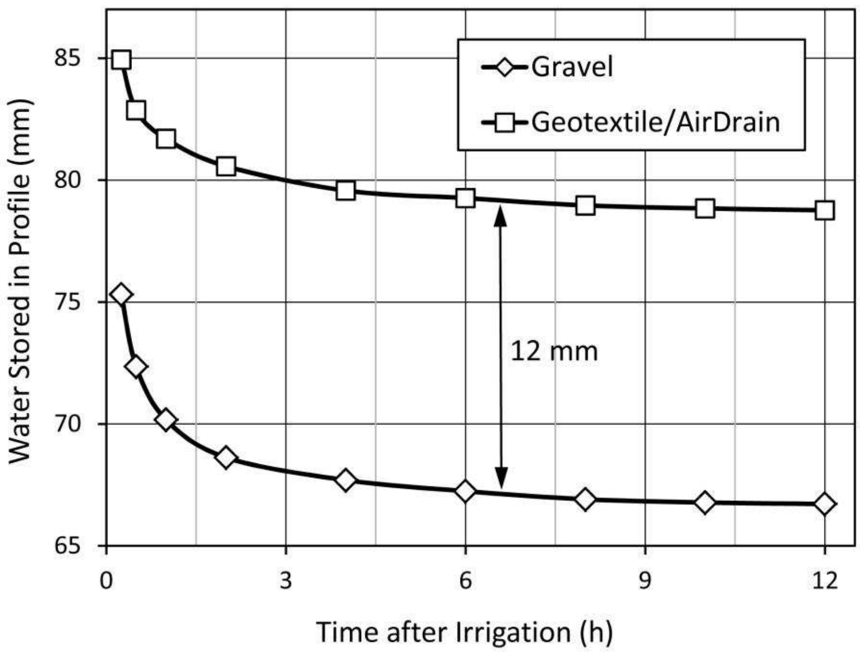

Figure 6. Temporal change in water stored in the 300-mm deep root zones atop gravel and atop geotextile/AirDrain in covered test greens. Water loss was by drainage only.

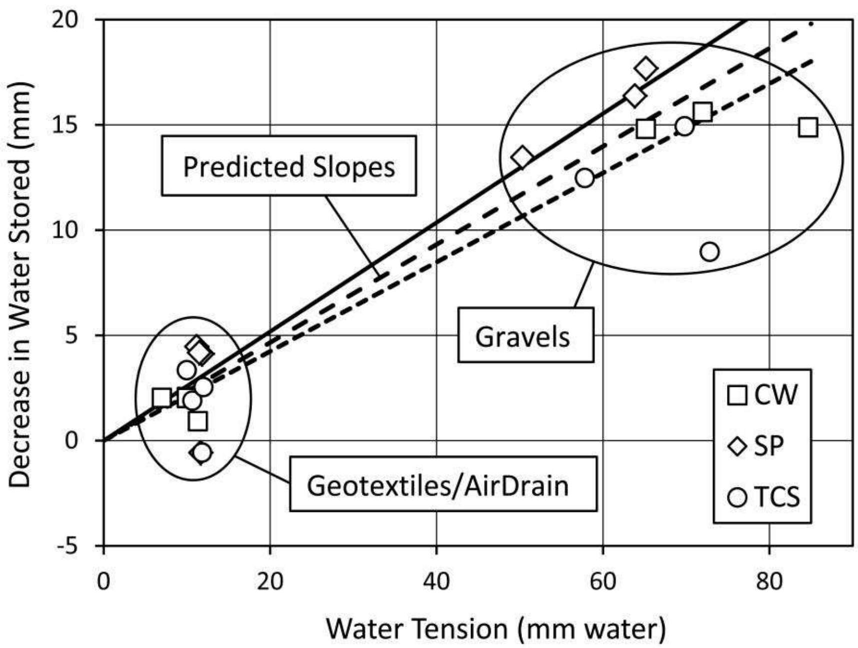

Figure 7. Water stored in the root zone with water tension at the bottom of the profile. The lines represent the slopes of the D vs. h_b relationships for the three root zone mixtures (from Eq. 1 and Fig. 2) and are not a regression lines for the data on the graph.

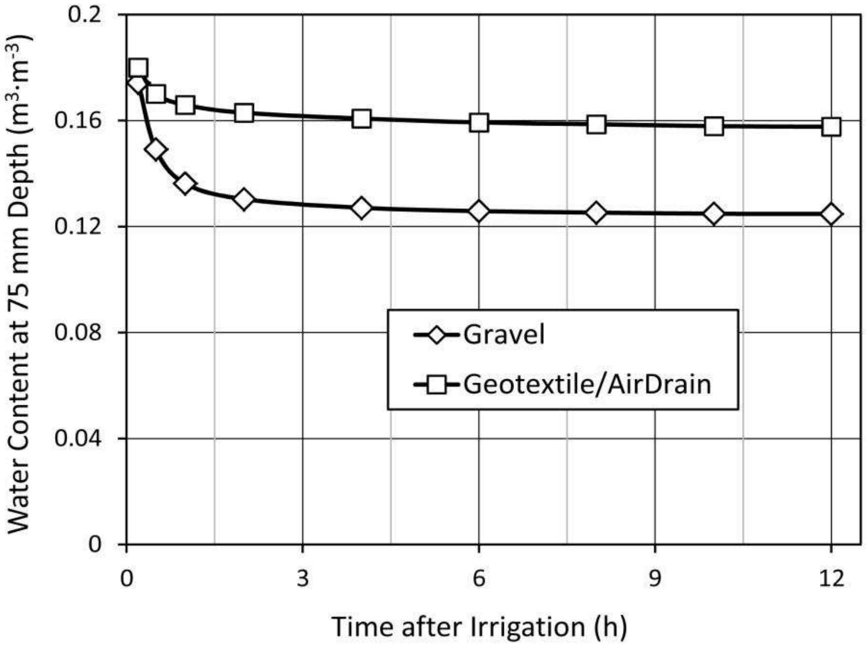

Figure 8. Temporal change in volumetric water content at 75-mm depth below the surface of the root zones atop gravel and atop geotextile/AirDrain in covered test greens. Water loss was by drainage only.

When the test greens were left uncovered, the differences in water stored in the root zone profiles remained constant following irrigation through several days' decline in stored water caused by evaporative loss (Fig. 9). These measurements on uncovered test greens were taken in the fall of the year when evapotranspiration rates were about 4 $mm \cdot d^{-1}$, so it took about 3 days to use the 13 mm difference in water stored in the profiles. That is to say, it took 3 days for water stored in the test greens constructed with geotextile/AirDrain to decline to a point where they had the amount of water initially in the test greens constructed with gravel-based drainage. In hot arid regions, the additional water stored might only last a day or two in the middle of summer, while in cool humid regions, it could last the better part of a week. It is worthwhile to note that additional water storage in the root zone could also be achieved by altering the texture of the sand or by adding a larger amount of water-holding amendments such as peat moss or calcined clay to the sand mixture. However, care would be needed to maintain an acceptable balance between capillary and air-filled porosity so as to avoid excessively wet conditions.

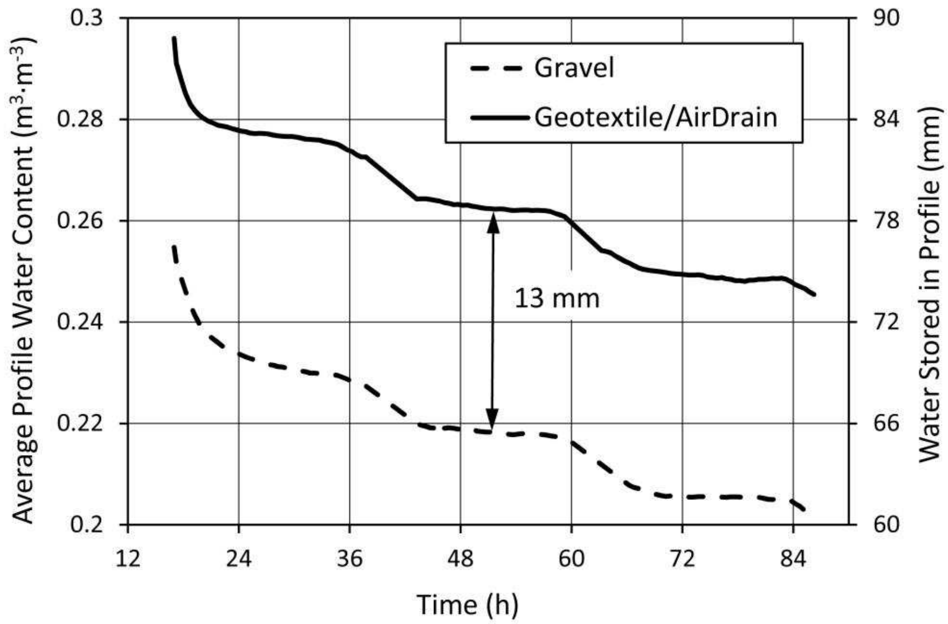

Figure 9. Temporal change in water stored in Sure Play root zone mixture atop gravel and atop geotextile/AirDrain in uncovered test greens. Stored water measured by vertical TDR probes. Water loss was by drainage and evapotranspiration. probes. Water loss was by drainage only.

The possibility that a geotextile might clog and limit drainage has been a major concern limiting the acceptance of geotextile use in putting greens. In our test greens, excess rainfall and irrigation water were quickly discharged through drainage (Fig. 10), regardless of the type of gravel or geotextile. In addition, during the yearlong study, the observations of water levels in the manometer-tensiometers did not indicate that positive pressure head developed on top of the gravels or geotextiles, that is to say, they never indicated that any of the gravels or geotextiles clogged and limited drainage of water out of the root zone.

CONCLUSIONS

With the same root zone mixture, a putting green constructed with Airfield Systems' design holds appreciably more water than a putting green constructed according to the standard USGA design. If the procedure for testing a root zone mixture to determine whether it meets USGA recommendations were to be used to test a mixture for an Airfield Systems' design putting green, the tension at which the air-filled porosity and capillary porosity were determined should be lowered by 50 mm water.

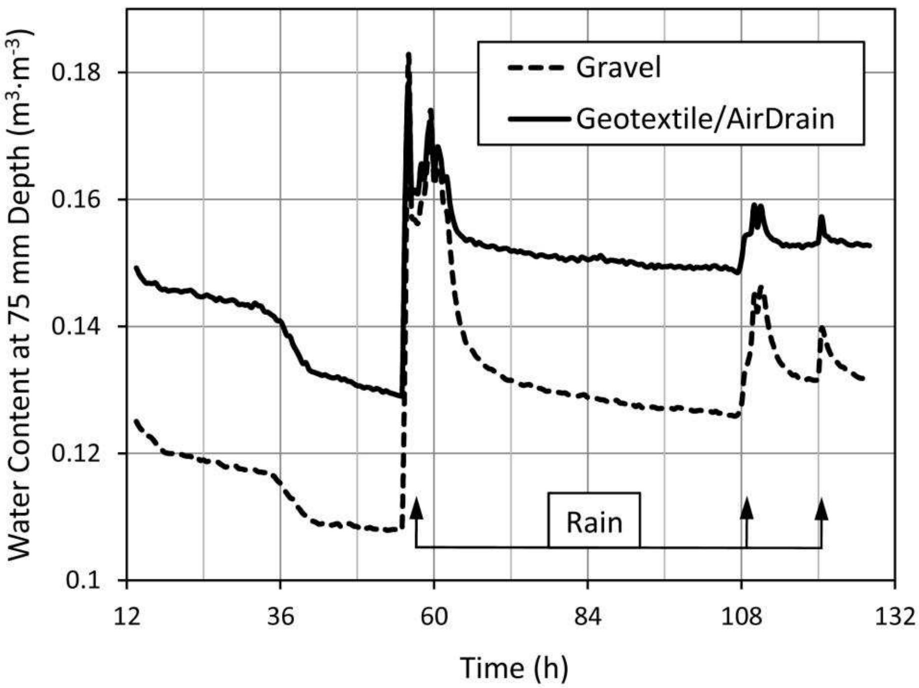

Figure 10. Temporal change in volumetric water content at 75-mm depth below the surface of Caylor White root zone mixture atop gravel and atop geotextile/AirDrain in uncovered test greens. Water content measured by horizontal TDR probes. Water loss was by drainage and evapotranspiration.

SECTION 2

RESTRICTING DOWNSLOPE WATER DRAINAGE IN USGA AND AIRFIELD SYSTEMS' DESIGNED PUTTING GREENS

INTRODUCTION

With a uniformly deep root zone across a putting green, capillary tension and the associated redistribution of water in the root zone after irrigation or precipitation can cause droughty areas to form on the upper portions of any slopes. To prevent water stress, these droughty areas can be watered more frequently than relatively flat areas, or the green may be designed from the start with shallower root zone zones or a different root zone mixture on the slopes. An alternative method to hold moisture in the upper portion of slopes would be to restrict the downslope movement of water through the root zone. Downslope movement of water through the root zone is governed by the degree of slope, and the capillary and hydraulic properties of the root zone mixture. When the root zone is saturated, it can transmit water at its maximum capacity. As water tension in the root zone increases the degree of saturation of the root zone mixture decreases. When the root zone is unsaturated, it transmits water at a rate much lower than the rate at saturation. Water tension in the root zone of a putting is near 0 at the bottom (at the root zone-drainage layer interface) and increases with height above that location. On flat portions of a putting green, water tension with height above the drainage layer is fairly uniform across the green. On sloping portions of a green, tension increases with distance upslope. As water tension in the root zone increases, water content of the root zone decreases, and the capacity of the root zone to transmit water decreases (Fig. 11). Our idea was that downslope movement of water in the root zone could be restricted by placing an impermeable barrier in the portion of the root zone with the capacity to rapidly transmit water (i.e., the lower portion).

In this study, we investigated using 200-mm (8 in) tall impermeable barriers to restrict downslope movement of water on a sloping green. In practice, these barriers would be place perpendicular to the slope, and could be installed when the green was constructed or be inserted where needed into an existing green.

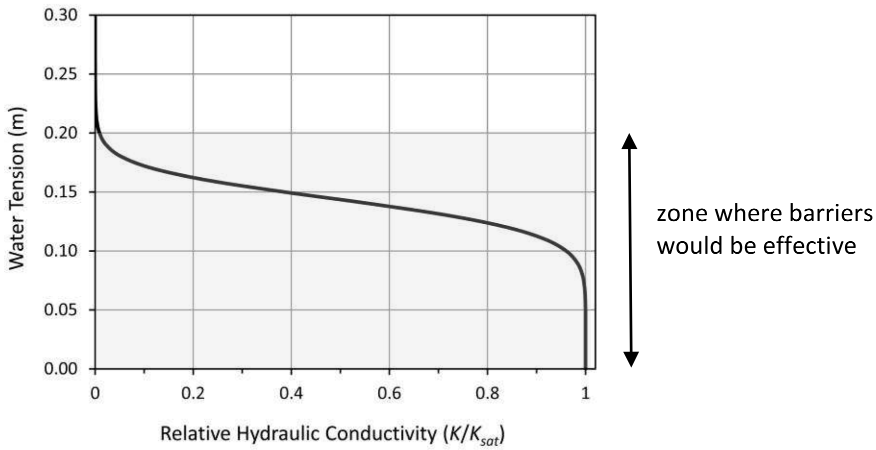

Figure 11. Example of the capacity for the root zone to transmit water (x-axis) as function of tension of the water in the root zone (y-axis).

EXPERIMENTAL DESIGN

A 3.5-m long by 0.4-m tall by 0.7-m wide box was constructed of 20-mm thick plywood. The box was sealed with a water-resistant paint and supported on a steel frame that produced a 0.05 $m \cdot m^{-1}$ slope along the 3.5-m length. The narrower ends of the box were affixed such that they were vertical when the box was supported on the sloping steel frame. A 0.5-mm thick PVC liner covered the inside bottom of the box and extended 0.1 m up the sides. The box was either filled with 0.3 m (1 ft) of silica sand over 0.1 m (4 in) of river gravel or 0.3 m of the same sand over a spunbond geotextile supported by a 25-mm (1 in) thick porous plastic grid (AirDrain, Airfield Systems, Edmond, OK). The bottom of the box contained a 20-mm wide cross-slope slot every 0.5 m that allowed collection of drainage flow for each 0.5-m long slope-wise portion of sand. Stainless steel mesh kept the gravel from falling through the drainage slots. Trays to collect the water from each portion of the sloping root zone were placed beneath the structure.

The sand used in the studies was obtained from US Silica's plant in Kosse, TX, and was packed moist in the box to a dry bulk density of 1.5 $Mg \cdot m^{-3}$. The geotextile was Type 097 Lutradur (Freudenberg Nonwovens, Durham, NC), a spunbond polyester having an areal density of 130 $g \cdot m^{-2}$. The reported apparent opening size of this geotextile was 198 μm (ASTM, 2004), and at 50 mm head pressure the reported water flux density through the fabric was 157 $L \cdot m^{-2} \cdot s^{-1}$ (ASTM, 2009).

The particle size distribution of the sand and the gravel were determined by dry sieve analysis. The sand root zone mixture had a particle size distribution that met USGA recommendations (Fig. 12). The gravel met the USGA recommendation for particle size and bridging when used with the sand without an intermediate (choke) layer of coarser sand. The relationship between water content of the sand and water tension in the sand was determined by segmenting 0.7-m tall by 75-mm diameter columns of the sand that had been watered to excess of holding capacity and allowed to drain for 24 hours after being cover with a plastic bag to minimize evaporation (Fig. 13).

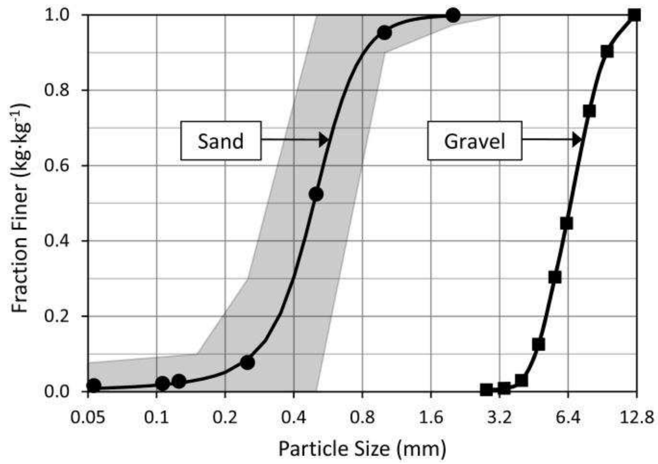

Figure 12. Particle size distributions of the sand and gravel used in the study. The shaded area represents the particle size limits for the root zone mixture as recommended by the USGA.

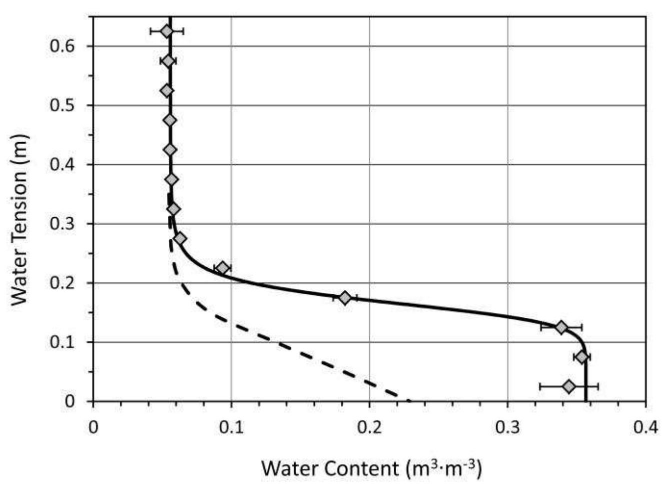

Figure 13. Relationship between water content and water tension for the root zone material. The solid line represents a curve fit of the model of Van Genuchten (1980). The dashed line represents the average water content of 0.3 m of root zone material above the location in the root zone having the given tension shown on the y-axis (e.g., if the bottom of a 0.3-m deep root zone were at 0.05 m tension, the average water content of the 0.3-m deep root zone would be about 0.18 $m^3 \cdot m^{-3}$).

Water was applied to the sand surface with a handheld sprinkler until water was draining from all slits in the bottom of the test box. The box was then covered with a PVC sheet to minimize evaporative loss of water. Changes in the slope-wise distribution of vertical-average water content in the sand root zone mixture system were monitored for 24 hours using a time domain reflectometry TDR system (Campbell Scientific, Logan, UT). The TDR probes were 0.3-m long (model CS605) and were installed vertically every 0.167 m, beginning at 0.11 m upslope from the lower end of the box. This arrangement placed 3 probes in each 0.5-m segment on the slope. Each probe measured a vertical average of the water content in the root zone profile at its location on the slope. The TDR probes were connected through coaxial multiplexers (model SDMX50) to the reflectometer (model TDR 100). The reflectometer was connected to a datalogger (model CR1000) that was programmed to record water contents at 5-min intervals.

After data were collected from the gravel and geotextile systems, 0.2-m tall, vertically oriented, cross-slope barriers made of 3 mm-thick polycarbonate sheet were placed in the bottom of the sand profile (Fig. 14). The barriers were sealed to the sides of the box with silicone caulk and blocked downslope movement of water in through the lower (saturated) portion of the sand profile. A barrier was placed just upslope of each horizontal slit in the bottom of the box, except for the slit at the low end of the box. When gravel was used as the drainage structure, the lower part of the barrier was at the gravel-sand interface. With the geotextile atop AirDrain treatment, the lower part of the barrier was in contact with the geotextile. As before, the sand in the box was watered until water discharged from all drainage slits, the box was covered to minimize evaporative loss of water, and changes in the slope-wise distribution of water content in the sand root zone mixture system were monitored for 24 hours. After viewing the water content data from the above treatments, an additional configuration that broke the downslope continuity of the geotextile was investigated. Segments of geotextile were installed so that they started 5 cm up the downslope sides of the barriers and stopped the same distance up the upslope side of a barrier. Installing the geotextile separated in this manner created a hydraulic discontinuity in the geotextile beneath each barrier.

Figure 14. Sloping test box with TDR water content probes (left) and excavated section showing subsurface clear plastic barrier in place at the bottom of the root zone profile (right).

RESULTS

Sand over gravel

Without barriers, water stopped draining from the all but the bottom cross-slope slot within an hour of termination of water application to the surface. Water continued to drain from the bottom slot over the 24-hour measurement period, but the rate decreased rapidly with time, and after 24 hours drips were infrequent. With barriers in place, water drained for a longer period of time from each 0.5-m segment and much less water drained from the bottom slot, suggesting that downslope movement of water was considerably hindered. Viewing the temporal trend of the water content at the upper portion of the slope, the effect of the barrier is evident (Fig. 15).

Sand over geotextile atop AirDrain

Similar to the gravel-based system without barriers, water stopped draining from the all but the bottom cross-slope slot within an hour of termination of water application to the surface of the system constructed with the geotextile/AirDrain drainage structure. Water continued to drain from the bottom slot over the 24-h measurement period, but the rate decreased appreciably with time. With barriers in place and a continuous sheet of geotextile, little difference was observed in where the water drained along the slope or in the temporal trend in water content at the upper portion of the slope (Fig. 16). This similarity in drainage with and without the barriers was unexpected and showed that the geotextile was as efficient as the lower 200 mm of sand in transporting water downslope. With the continuity of the geotextile broken beneath each barrier, water remained in the upper portion of the slope.

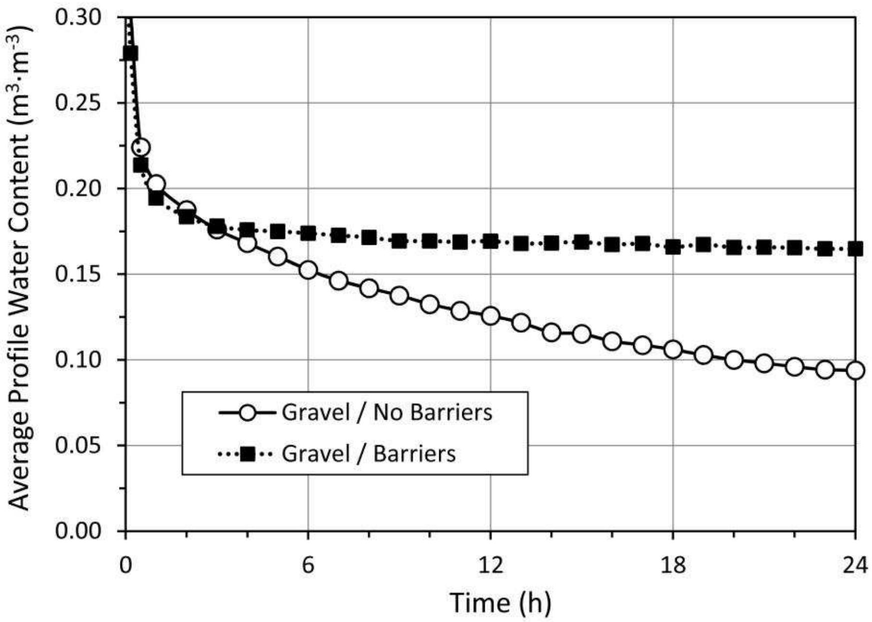

Figure 15. Average profile water content measured with the two sensors located at the top of the slope (i.e., 3.1 and 3.3 m from the bottom of the slope) for root zone material over gravel with and without barriers.

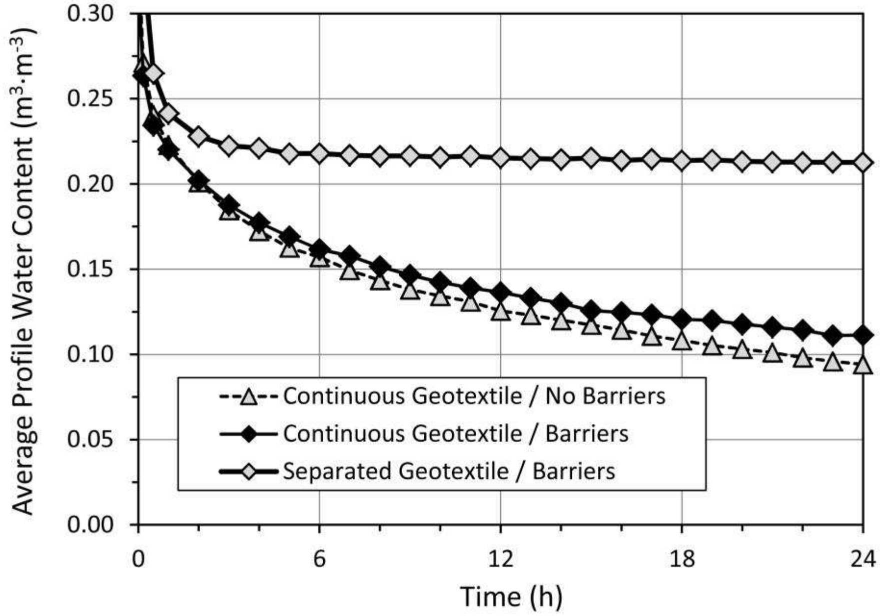

Figure 16. Average profile water content measured with the two sensors located at the top of the slope (i.e., 3.1 and 3.3 m from the bottom of the slope) for root zone material over geotextile/AirDrain with and without barriers.

Water Retention

When the subsurface barriers were in place, more water was held along the entire slope (Fig. 17). If the downslope continuity of the geotextile was broken, the sloping green containing the Airfield Systems' design containing subsurface barriers held the most water. When the continuity of the geotextile was left intact, the USGA design containing subsurface barriers held more upslope water, but only when the distance was >2 m upslope. As with the results reported in Section 1 of this report, it was clear from the water contents at the bottom of the slopes of the different treatments that the root zone of the green constructed with Airfield Systems' design would hold more water on a non-sloping green.

CONCLUSION

It was feasible to prevent droughty areas from appearing on the upper portion of a putting green slope by installing impermeable subsurface barriers, at the bottom of the root zone and perpendicular to the slope, to restrict downslope movement of water.

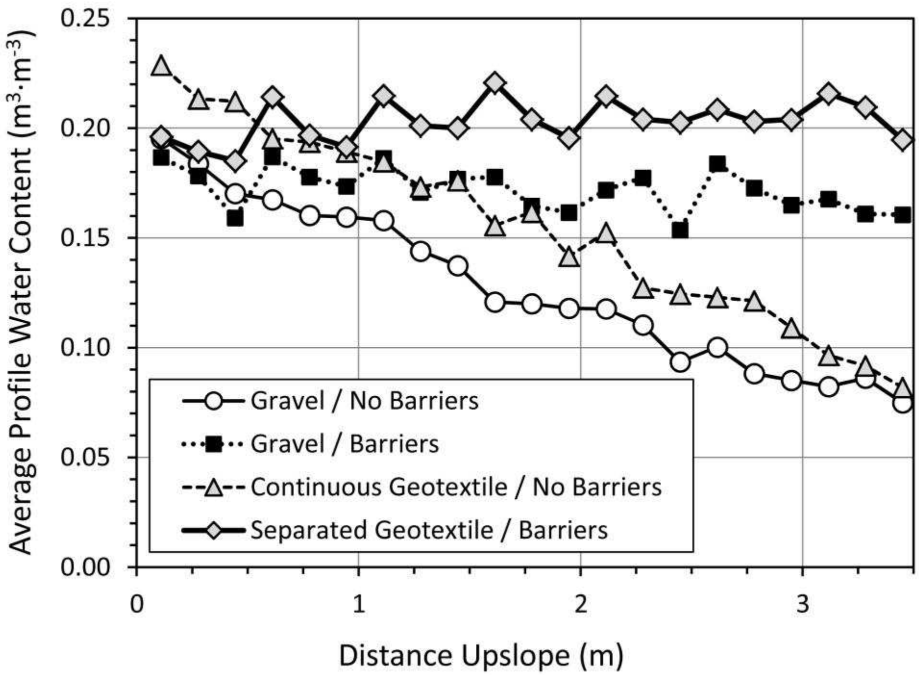

Figure 17. Average profile water content as a function of distance upslope for the four tested configurations.

SECTION 3

CLOGGING OF GEOTEXTILES

INTRODUCTION

Airfield Systems' design for a putting green uses a geotextile atop their AirDrain geocell drainage structure in place of the gravel drainage layer in the standard USGA design. One of the reoccurring concerns in acceptance of using a drainage structure that incorporates at geotextile is whether or not the geotextile will clog over time and restrict water drainage from the putting green. There are several commercially available geotextiles that are suitable to support the root zone in putting greens. These geotextiles are most often made from filaments of materials such as Polypropylene (PP), Polyvinylchloride (PVC), Polyester (P) and Polyethylene (PE), which are woven, tangled, or bonded. To function properly, the geotextile must retain the root zone mixture while allowing water to flow freely through its pores. If the pores of the geotextile become clogged with fine particles, the geotextile can lose an appreciable fraction of its permeability. Restricted drainage of water from the root zone leads to poor growth of turfgrass and increased time for resumption of play after rainfall.

Proper functioning of a putting green constructed with a sand-based root zone atop geotextile depends on the physical properties of both the root zone mixture and the geotextile. The geotextile must have pores that are fine enough to prevent the root zone mixture from migrating through while being coarse enough to allow water to freely pass. The most common way of describing a geotextiles' pore size distribution (Fig. 18) is the apparent opening size (AOS). The AOS refers to the diameter or width of a pore (opening) where 95 % of the pores in the geotextile are smaller, often symbolized as O_{95} (ASTM, 2004). AOS essentially gives an estimate of the size of the largest particle that can pass through the geotextile.

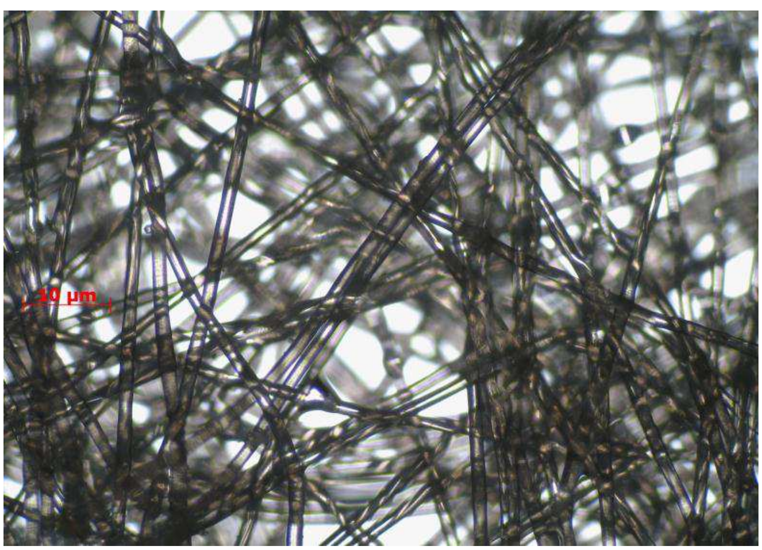

Figure 18. Close-up photograph of a spunbond geotextile showing the variation in pore sizes within the fabric.

There are three main types of commercially available geotextiles, needle punched, woven, and spunbond (Fig. 19). Needle punched material is produced by entangling staple fibers with barbed needles while with spunbond textiles, the fibers are heat or chemically bonded.

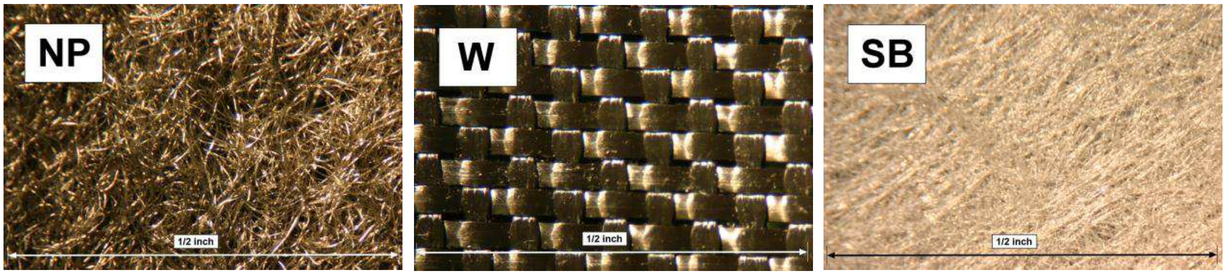

Figure 19. Close-up photographs of the three types of geotextiles used to test for clogging of geotextile pores: NP – needle punched, W – woven, SB – spunbond.

Numerous studies, primarily laboratory based, have been conducted to determine the compatibility of particular soil-geotextile combinations. Few studies, though, have been conducted to assess changes in drainage of golf green root zone mixture atop geotextile. The purpose of this study was to combine geotextiles of different construction type and different AOS with root zone mixtures having different particle-size distributions. The research was focused on the temporal changes in drainage in the first year after establishment of a putting green, when most of the migrations of fines that might clog the fabric are expected to occur. The objectives were to determine temporal changes in whole-system drainage rates from test columns that contained particular combinations root zone mixtures and geotextiles, and to assess whether any temporal changes drainage were due to clogging of geotextiles.

EXPERIMENTAL DESIGN

Laboratory studies were conducted at Texas A&M University, College Station, from June 2008 to August 2009. Test columns were constructed from SDR PVC pipe of an inner diameter of 150 mm (6 in) and a length of 350 mm (14 in). A circular piece of geotextile about 40 mm larger in diameter than the PVC pipe was fitted over one end of a column, and a flat bottom end cap with a disk of AirDrain was pulled tightly over both the geotextile and column (Fig. 20). Columns were fitted with tensiometer-manometers for observations of pressure build up at the sand-geotextile interface, which would indicate geotextile clogging.

One hundred eighty permeameters were constructed from 150-mm (6 in) inner diameter by 350-mm (14 in) tall PVC pipe and end caps. Each permeameter was filled with 300-mm deep root-zone mixture over a geotextile supported on a disk of AirDrain, a 25-mm deep plastic geocell. A tensiometer-manometer was placed on top of the geotextile in each test cell before it was filled with the root zone mixture. The tensiometer-manometer acted as a gauge of the pressure or tension that developed at the root zone-geotextile interface. Positive pressure for extended times after irrigation or precipitation would indicate clogging to a degree that flow of water was restricted by the fabric.

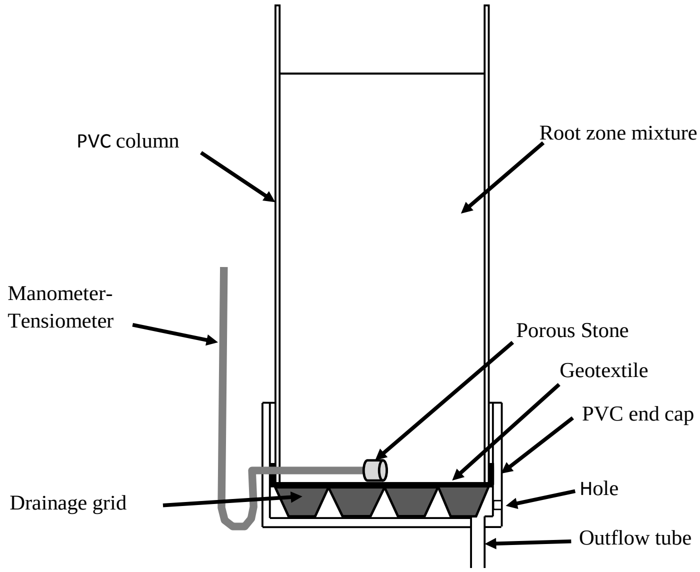

Figure 20. Schematic diagram of a longitudinal section of a test column (left). View into a test column showing a tensiometer-manometer atop a geotextile before the column was filled with root zone mixture (right).

Ten geotextiles were evaluated: two woven, three spunbond, and five needle punch (Table 3). Apparent opening sizes (AOS) of the ten geotextiles ranged from 0.150 to 0.425 mm.

Table 3. Geotextiles used in the study.

Geotextile	Supplier	Type†	Material‡	AOS§ (mm)	Water Flow Rate¶ (mm/s)
GSENW16	GSE	N	PP	0.150	34
GSENW10	GSE	N	PP	0.150	58
NW401	Propex	N	PP	0.212	95
NW1001	Propex	N	PP	0.150	58
NW351	Propex	N	PP	0.300	102
WM104F	Propex	W	PP	0.212	12
FW404	TenCate	W	PP	0.425	48
3301L	Fiberweb	S	PP	0.3	65
3341G	Fiberweb	S	PP	0.24	58
Lutradur	Freudenberg	S	P	0.198	157

† N-Nonwoven needle punched; W-Woven; S-Spunbond
‡ PP-Polypropylene; P-Polyester
§AOS determined by ASTM D4751-04 (ASTM, 2004)

¶ Water Flow Rate determined by ASTM D D4491- 99a(2009) (ASTM, 2009)

Six root-zone mixtures with differing distributions of fines (Fig. 21, Table 4) were created by blending three parent materials with differing particle size distributions, two sands and a sandy clay loam. One of the parent materials' particle size distributions fell in the middle of the USGA specifications. The other two parent-materials exceeded the specified limits for fine and very fine sand. Root zone mixtures that pushed or exceeded USGA limits for fines were purposely targeted because fines are the likely particles that would migrate and clog geotextiles.

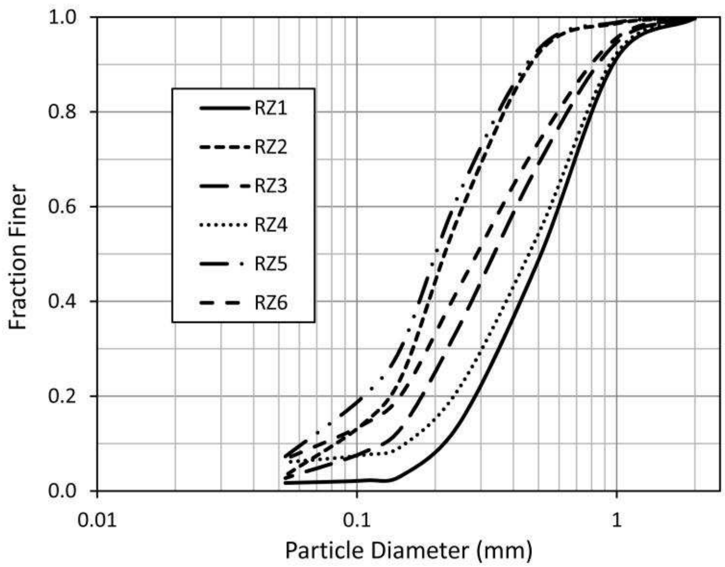

Figure 21. Particle size distributions of the 6 root zone mixtures tested.

Table 4. Saturated hydraulic conductivity (ASTM, 2006) and coefficient of particle size uniformity of subsamples of the root zone mixtures prior to the experiment.

Root Zone Mixture	Saturated Hydraulic Conductivity μm/s (in/h)	Coefficient of Uniformity†
RZ1	440 (63)	2.55
RZ2	74 (10)	3.17
RZ3	110 (15)	3.48
RZ4	85 (12)	4.35
RZ5	31 (4.4)	3.87
RZ6	14 (1.9)	5.96

† C_U is a descriptor of the shape of a particle size distribution curve.

Each geotextile was tested in combination with all six root-zone mixtures (180 test columns). After being mixed in a cement mixer, the root zone mixtures were packed into the pre-assembled test columns. This was done in three layers to a total depth of 300 mm, the top of the first and second layers being scarified to reduce layering effects. The test columns were placed on benches, tilted slightly and fitted with drainage tubes to facilitate drainage water collection and data acquisition.

Synthetic rainwater was used throughout the entire study for all regular irrigation and data collection. The columns were initially irrigated with 76.2 mm (3 in) depth of water (applied by hand) to facilitate saturation and initiate drainage. To simulate heavy watering during the establishment of turfgrass cover, for the first two weeks, the columns were irrigated with 19 mm (3/4 in) of water. This amount was half every two weeks until the resultant amount was 4.8 mm (3/16 in), which was maintained for the remainder of the study. Measurements of drainage rates began 1 month after the initiation of the study and continued for 1 year. Sixteen hours before drainage measurements, the test columns were irrigated with a 25 mm depth of water, covered and allowed to drain so that they were at maximum water holding capacity. To collect drainage data, a 25 mm depth of water was added to the columns. The cumulative mass of water drained from an individual column over 1-h was recorded every 5 seconds on an electronic balance (Model SP2001Ohaus Scout Pro, Ohaus, Pine Brook, NJ) connected to a computer through a USB hub. Before drainage data collection the tensiometer-manometers were primed with water. Water levels in the tensiometer-manometer tubes were monitored over the course of the hour drainage. In addition to the 1-h measurements of drainage rates, the amount of water drained over the 24-h period beginning at the start of the 1-h drainage rate measurements were recorded.

All the particles in the drainage waters collected from individual columns were flocculated with sodium chloride and accumulated. At the end of the study, the salt solution was siphoned off and the accumulated particles were dialyzed in a membrane having a pore size range of 12 to14 kDa (Spectra/Por 4, Spectrum labs, Rancho Dominguez, California) to remove salt. The dialyzed particles were subsequently re-dispersed with 10 mL of sodium meta-phosphate (50g/L), mixed with a magnetic stirrer and analyzed for particle size on a laser particle size analyzer. The remaining particles were oven dried at 105 °C and weighed.

Statistical differences in the effects of treatments were assessed using the *TukeyHSD* and *aov* statistical functions in R (R Development Core Team, 2009).

Figure 22. Columns used to test for clogging of geotextile pores (upper left), monitoring drainage rates (upper right), collection cups for drainage water (lower left), and cups used to flocculate particles passing through the columns (lower right).

RESULTS

During the course of the 1-year, we did not observe positive pressure build atop the geotextiles for any appreciable time, indicating that the geotextiles did not clog. When drainage rates from the test runs were averaged across root-zone mixtures for each of the geotextiles, no significant differences (95% confidence) in drainage rates were observed. When drainage rates from the test runs were averaged across geotextiles for each of the root-zone mixtures, significant differences in drainage rates were observed. During the course of the study, permeability of the root zone mixtures in some of the test columns declined appreciably, but it did not appear through observations (Figs. 23 and 24) and statistical analyses (Table 5) that the decline was due to clogging of the geotextiles, rather it appeared it was due to clogging of the root zone mixtures themselves. To test whether the root zone mixtures were clogging, those test columns that showed an appreciable reduction in permeability were subject to further tests. Saturated conductivity of the columns in question were evaluated with all the root zone mixture in them, then reevaluated with the surface 50, 100, and 150 mm of mixture removed. If no clogging had occurred, the saturated hydraulic conductivity of the root zone would not change when mixture was excavated. We found, though, a considerable increase in saturated hydraulic conductivity of the root zone mixtures in the columns in question as mixture was removed from the surface (Fig. 25). This increase indicated that the root zone mixtures themselves were clogging.

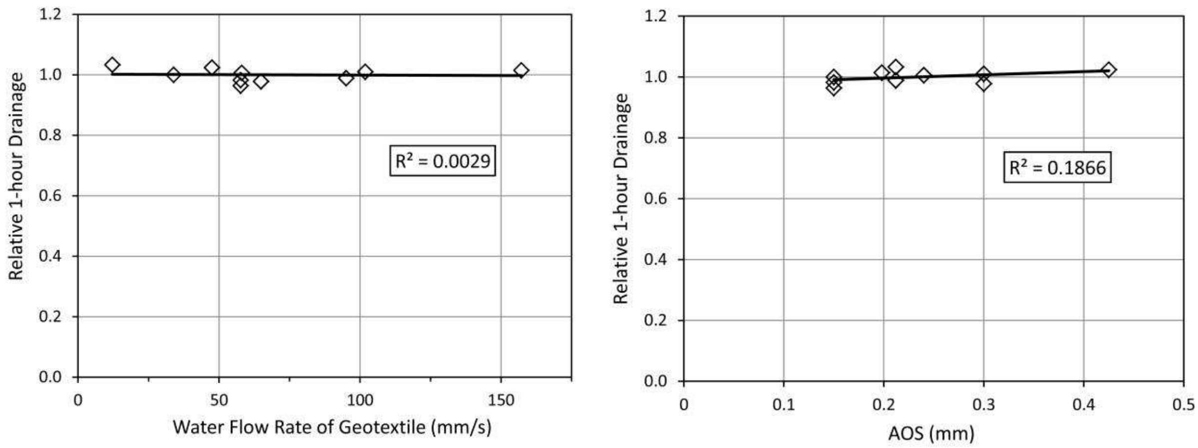

Figure 23. Relative drainage rate of average of all root zone mixtures after 6-months as a function of the geotextile manufacturer's reported water flow rate (left) and AOS (right) of the textiles.

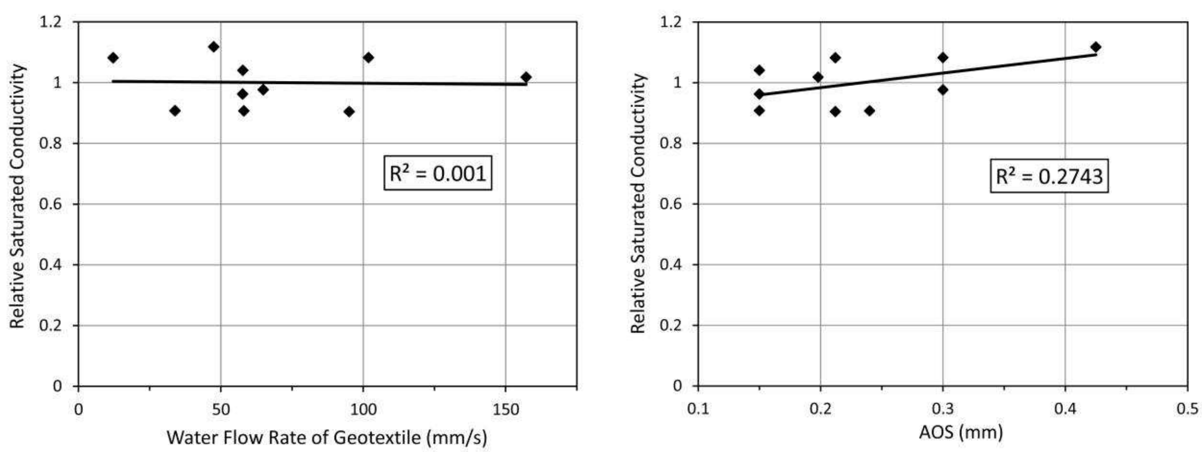

Figure 24. Relative hydraulic conductivity of Root Zone Mixture 1 after one year as a function of the geotextile manufacturer's reported water flow rate (left) and AOS (right) of the textiles.

Table 5. Analysis of Variance of the in situ saturated hydraulic conductivity of the root zone mixtures after 1 year of irrigation.

Source of variation	P(>F)
Root Zone Mixture	<0.001
Geotextile	0.326
Root Zone Mixture X Geotextile	0.999

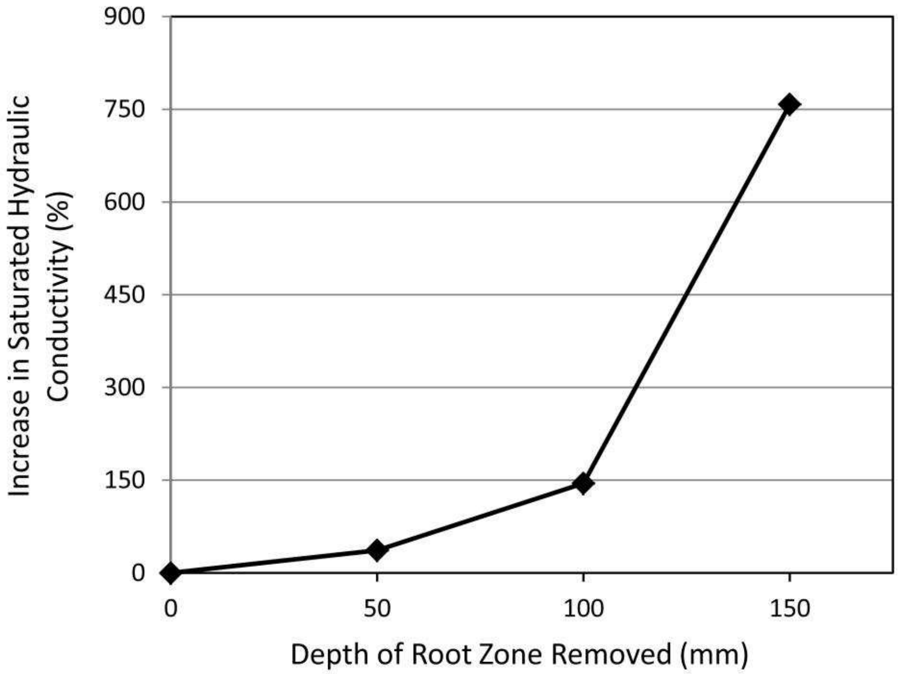

Figure 25. Average increase in permeability of the root zone with depth in columns that showed appreciable decrease in permeability with time over the duration of the 1-year experiment. An increase with depth indicates clogged root zone pores above that depth.

The quantity and particle size distribution of the particles that passed through the geotextiles were affected by the root zone mixtures, but not by the geotextiles (Tables 6 and 7, and Fig. 26). The effect of root zone mixture, and not of geotextile, on the size of particles in the drainage water was especially clear when particles from root zone materials with vastly different particle sizes passing through geotextiles with vastly different AOSs were compared (Fig. 27).

Table 6. Analysis of Variance of the d_{90} of particles in the drainage water from the test columns.

Source of variation	P(>F)
Root Zone Mixture	<0.001
Geotextile	0.625

Table 7. Analysis of Variance of the cumulative mass of particles in the drainage water from the test columns.

Source of variation	P(>F)
Root Zone Mixture	<0.001
Geotextile	0.999
Root Zone Mixture X Geotextile	0.999

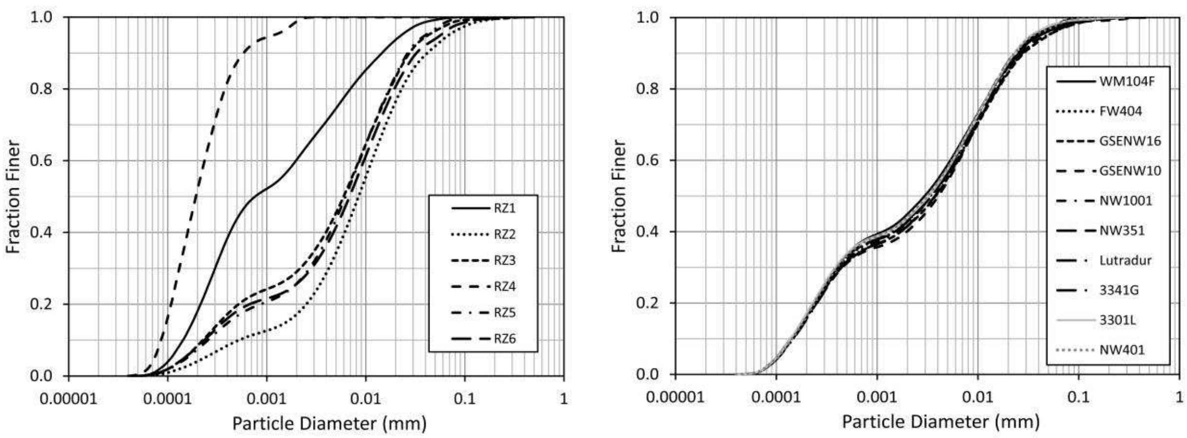

Figure 26. Size distribution of particles passing out of the root zone mixtures and through the geotextiles - the effects of root zone mixture (left), the effects of geotextile (right).

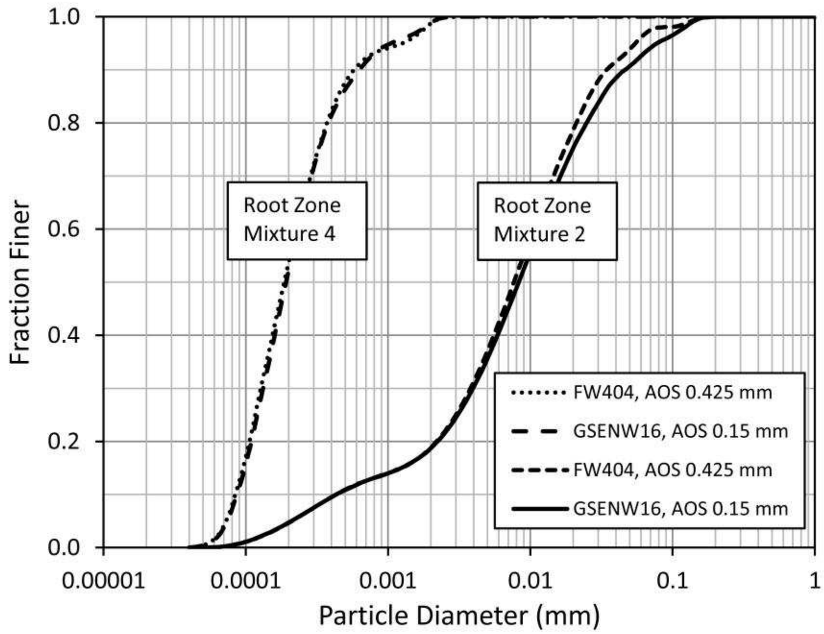

Figure 27. Size distribution of particles passing out of Root Zone Mixtures 2 and 4 and through the Geotextiles FW404 and GSENW16.

CONCLUSIONS

Particle size distribution of the root-zone mixtures affects drainage rate in an Airfield Systems' designed putting green, as expected, but apparently much more through clogging of pores within the root zone itself rather than through clogging of pores in the geotextile.

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