Water Retention in Root-zone Soil Mixtures of Layered Profiles Used for Sports Turf

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Abstract. Where coarse-textured materials, such as gravel, underlie the root-zone layer of sports turf soil profiles, water retention in the root-zone layer is increased. The objective of this research was to determine the water retention characteristics in sand and sand : peat mixtures placed over coarse-textured layers and to determine how sand particle size and type of peat in the mixtures influenced water distribution after drainage. Soil profiles consisted of 30 cm of sand or sand : peat mixtures over 5 cm of predominantly coarse and very coarse sand, which in turn was over 10 cm of gravel. Excess water was added to the profile and allowed to drain for 24 or 48 h, following which water content and air-filled porosity (AFP) in the mixtures were evaluated. Regardless of the root-zone mixture, the coarse-textured sublayers resulted in a wet zone in the lower portion of the root-zone mixture. An unamended, predominantly medium and coarse sand, when used in the 30-cm root-zone layer, maintained $\approx 10\%$ AFP in the lower 6 cm after drainage. Sand : peat mixtures using this sand generally maintained 3% to 8% AFP in the lower 12 cm of the root-zone layer. An unamended, predominantly fine and medium sand root-zone layer had $\approx 6\%$ AFP in the lower 9 cm and sand : peat mixtures using this sand had $< 5\%$ AFP in the lower 12 to 18 cm of the root-zone layer, with significant portions remaining at or near saturation after 24 or 48 h of drainage.

Sports turf areas pose difficult soil problems for turf managers. These soils are subjected to frequent traffic, often under the most adverse of soil strength conditions. Natural soil structure is continually broken down, resulting in lowered water infiltration and oxygen diffusion rates and sluggish internal drainage. In areas where a dense turfgrass cover is essential despite heavy traffic, various methods have been used to modify the soil to help it resist the detrimental effects of excessive compaction. One of the most popular methods is to install a layered soil profile in which a root-zone soil mixture of high sand content is underlain by a coarse-textured layer such as sand or gravel [Goss and Cook, 1983; U.S. Golf Assn. (USGA) Green Section, 1960, 1993]. The sand and gravel layers act as a conduit for excess water to get to the drain tile quickly and as a barrier to downward flow of water under unsaturated conditions, thus increasing the effective water holding capacity of the root-zone soil mixture. The coarseness of the underlying layer and the depth to the coarse layer affect the water retained in the

overlying mixture (Miller, 1973; Taylor et al., 1993).

Since publication of the USGA specifications in 1960, characteristics of root-zone soil mixtures have been studied extensively. Recommended soil mixtures have always relied on high sand content to maintain adequate water and oxygen flow rates after compaction. Since 1960, the amount of sand in recommended mixtures has increased. Swartz and Kardos (1964) suggested a minimum of 70% sand by weight was sufficient to maintain adequate percolation rates in laboratory-packed soil mixtures. Davis et al. (1970) recommended sand : organic amendment mixtures, although their sands generally included some silt and clay. In 1973 the USGA Green Section revised their specifications by increasing the desired rate of water flow in laboratory-packed samples; in most cases, this meant increasing the sand content of soil mixtures. Taylor and Blake (1979) suggested that suitable sand : soil : peat mixtures required at least 87% sand content by weight to maintain adequate physical properties for turf growth after compaction. Waddington et al. (1974) demonstrated that sand characteristics had an impact on mixture properties after compaction of field plots. Generally, it took less uniform, coarse sand to adequately modify soil as compared to using a finer, less uniform, mortar sand.

There has been some disagreement on the best sands to use in soil mixtures. Daniel and Freeborg (1979) recommended fine to me-

dium sands (0.1 to 0.6 mm in diameter), Davis et al. (1974) recommended sands of predominantly medium size (0.25 to 0.50 mm in diameter), the USGA Green Section (1993) and Blake (1980) recommended sand of predominantly medium and coarse size (0.25 to 1.0 mm in diameter).

Most research has been aimed at maintaining adequate water and oxygen flow rates in the soil mixture after compaction. No research has been conducted to determine the amount of water held in root-zone soil mixtures placed over layers of sand and gravel. There has been concern that the area of the root-zone soil mixture immediately over the coarse sand layer can remain saturated for extended periods and may limit root growth and contribute to development of other problems.

The objective of this research was to determine water retention characteristics in soil mixtures over sand and gravel and to determine how sand particle size and type of peat in soil mixtures affect the water distribution after drainage.

Materials and Methods

In this laboratory experiment soil profiles were constructed with a 30-cm layer of soil mixture placed over sublayers corresponding to the 1989 USGA specifications. Excess water was introduced and the profile allowed to drain for 24 or 48 h. After drainage, the profile was sectioned in 3-cm increments to determine the water content and AFP of each section of the root-zone soil mixture.

Six root-zone mixtures (Table 1) were used that consisted of 1) unamended sand with particles between 0.25 and 1.0 mm in diameter (medium and coarse sand) the predominant size, hereafter called the coarser sand; 2) an 80:20 (v/v) mixture of the coarser sand and sphagnum peat; 3) an 80:20 (v/v) mixture of the coarser sand and reed-sedge peat; 4) unamended sand with principally fine and medium sand particles (0.10 to 0.50 mm in diameter), hereafter called the finer sand; 5) an 80:20 (v/v) mixture of the finer sand and sphagnum peat; and 6) an 80:20 (v/v) mixture of the finer sand and reed-sedge peat. The peats consisted of a baled, Canadian sphagnum peat (Langley Peat North, Ceba Beach, Alberta, Canada) and processed, baled Dakota reed-sedge peat (Pioneer Peat, Grand Forks, N.D.). Organic matter contents of these sphagnum and reed-sedge peats were 87% and 94%, respectively, as measured by percent loss in a muffle furnace at 450 °C. The reed-sedge peat was a processed peat with small particles, much finer than the fibrous sphagnum peat. The result was that 80 sand : 20 reed-sedge peat mixtures had higher organic matter contents on a mass basis than the 80 sand : 20 sphagnum peat mixtures. This reed-sedge peat would likely not represent unprocessed reed-sedge peats of larger fragments.

The soil profiles were constructed in 5.1-cm-inside-diameter plexiglass sections. The bottom section, 10 cm high, with a nylon mesh attached to the bottom, was filled with gravel particles between 2 and 12 mm in diameter. A

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Table 1. Particle size distributions of sand and sand : peat mixtures used in the constructed soil profile.

Mixture	Distribution (kg·100 kg ⁻¹)									Uniformity coefficient ^a (mm·mm ⁻¹)	Organic matter (kg·100 kg ⁻¹)
	Particle diam (mm)										
	<0.002	0.002–0.02	0.02–0.05	0.05–0.10	0.10–0.25	0.25–0.5	0.5–1.0	1.0–2.0	2.0–5.0		
Coarser sand	1.3	0.7	0.8	2.1	22.3	29.3	33.8	9.5	0.2	4.3	0.07
Coarser sand/ sphagnum peat	1.3	0.8	1.0	1.7	19.1	27.3	35.2	13.4	0.2	4.8	1.34
Coarser sand/ reed-sedge peat	1.4	1.2	1.4	1.6	18.1	25.7	36.0	14.1	0.5	4.8	2.98
Finer sand	1.2	0.6	0.7	2.6	34.4	52.3	6.4	0.3	0.4	2.9	0.06
Finer sand/ sphagnum peat	1.0	1.0	0.9	4.7	35.1	46.2	8.2	1.4	1.5	3.0	1.10
Finer sand/ reed-sedge peat	1.3	1.0	1.1	4.2	35.3	48.7	6.8	1.4	0.3	2.9	2.32
Pooled SD ^b	0.2	0.3	0.2	0.6	1.3	1.0	0.9	0.7	0.3	0.1	0.09

^aDiameter at 60% accumulation/diameter at 10% accumulation on a particle size accumulation curve.^bStandard deviation values pooled from all sands and sand : peat mixtures.

5-cm-high section filled with coarse and very coarse sand (77% of particles between 0.5 and 3.0 mm in diameter) was placed on the gravel and firmed. A 30-cm layer of soil mixture was built up over the sand layer using ten 3-cm-high sections of plexiglass containing the desired soil mixture.

Packing the soil mixture into each 3-cm section consisted of adding water to a bulk sample of soil mixture until the mass water content was 0.10 g·g⁻¹. Two empty cylinders, each 3.0 cm high × 5.1 cm inside diameter, were stacked vertically and soil mixture added until the cylinders were almost full. The mixture was frequently disturbed with a metal spatula during filling to prevent buildup of trapped air. A 4.54-kg drop hammer was placed in the upper cylinder and dropped through a distance of 0.46 m once, giving a packing energy of 1.0 J·cm⁻² of soil mixture surface. The drop hammer was removed and the upper cylinder was removed by cutting through the soil mixture with a knife. The bottom core, full of packed soil mixture was used to construct the profile.

After 10 sections of soil mixture were built up over the coarse sand, an additional empty cylinder, with a moist sponge in the bottom to protect the soil surface during water additions, was placed on top and taped to the upper soil mixture section. Another plexiglass cylinder, slightly larger and split vertically, was clamped around the entire profile to stabilize the sections in place. Water was then ponded on the surface. After continual ponding for 0.25 h, the water infiltration rate was determined by measuring the time for the ponded water to drop through a distance of 1.0 cm.

The profiles were then allowed to drain for either 24 or 48 h. After drainage, the soil mixture layer of the profiles was sectioned in 3-cm increments and moist mass as well as mass after drying at 105 °C were determined. Mass water content and bulk density for each section were determined, from which volumetric water content and AFP were calculated by assuming a soil mixture particle density of 2.65 Mg·m⁻³.

Three replications of each treatment were prepared and evaluated. In analyzing the results of the experiment, infiltration rate, bulk density, and water held in the soil mixture

layer after drainage were analyzed with a two-factor analysis of variance, factors being soil mixture and drainage period. The main effects due to soil mixtures were divided into the following orthogonal contrasts to determine the effects of sand particle size and peat: mixtures with the coarser sand vs. mixtures with the finer sand (Mix 1, 2, 3 vs. 4, 5, 6); peat vs. no peat in coarser sand (Mix 1 vs. 2 and 3); peat vs. no peat in finer sand (Mix 4 vs. 5 and 6); sphagnum peat vs. reed-sedge peat in coarser sand (Mix 2 vs. 3); and sphagnum peat vs. reed-sedge peat in finer sand (Mix 5 vs. 6).

Results and Discussion

The main effect contrasts showed that sand significantly affected bulk density, with mixtures composed of the finer sand packing to higher bulk densities than those composed of the coarser sand (Table 2). For either sand, unamended sand packed to higher bulk densities than sand : peat mixtures and sand : reed-sedge peat mixtures packed to higher bulk densities than sand : sphagnum peat mixtures.

Sand type had a significant effect on infiltration rates, with mixtures using the coarser sand maintaining higher infiltration rates than those of the finer sand (Table 2). Where the coarser sand was used in the mixtures, mixing either peat type with sand significantly re-

duced infiltration rate as compared to unamended sand. Although peat decreased the bulk density and thus increased total porosity, with this sand it did not increase the pore sizes in the mixture. When the finer sand was used in the mixture, sphagnum peat increased infiltration rate while reed-sedge peat decreased infiltration rate as compared to unamended sand.

Using either type of sand, mixtures containing reed-sedge peat had lower infiltration rates than mixtures containing sphagnum peat, an indication, along with bulk density results, that the reed-sedge peat was filling pores between sand grains more than was sphagnum peat. The reed-sedge peat used in this experiment was a screened, processed peat with small particles, much finer than the fibrous sphagnum peat. Unprocessed reed-sedge peat of larger organic fragments could be expected to behave differently.

Bulk density and water infiltration rates indicate that the coarseness of the sand particles was more important than the differences in uniformity of the two sands. As measured by uniformity coefficient (d_{60}/d_{10}) the finer sand was more uniform (Table 1). Generally, more uniform sands result in lower bulk densities and higher infiltration rates (Waddington et al., 1974). The coarseness of particles also affects these properties and was more impor-

Table 2. Bulk density, infiltration rates, and water held in the soil mixtures after 24 or 48 h of drainage.

Soil mixture	Bulk density (Mg·m ⁻³)	Infiltration rate (m·h ⁻¹)	Water retained (cm)	
			Hours after drainage	
			24	48
Coarser sand	1.46	2.21	5.3	5.2
Coarser sand/ sphagnum peat	1.31	2.05	8.8	7.6
Coarser sand/ reed-sedge peat	1.39	1.24	9.2	9.4
Finer sand	1.50	1.32	7.1	6.8
Finer sand/ sphagnum peat	1.34	1.74	10.7	10.2
Finer sand/ reed-sedge peat	1.41	1.03	11.5	11.2
Contrasts				
1, 2, 3 vs. 4, 5, 6	***	***	***	***
1 vs. 2, 3	***	***	***	***
2 vs. 3	***	***	NS	***
4 vs. 5, 6	***	NS	***	***
5 vs. 6	***	***	**	***

NS, ***, ***Nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively.

tant than uniformity; thus, the coarser sand had lower bulk densities and higher infiltration rates despite being less uniform.

Water held in the 30-cm soil mixture layer, expressed as a depth of water, decreased slightly between 24 and 48 h of drainage (Table 2). The differences between drainage periods, however, appeared to be inconsequential to the performance of the soil mixtures. The finer sand increased the amount of water retained in root-zone soil mixtures, as compared to the coarser sand. In unamended sand (Mixes 1 and 4), the finer sand increased the total water held by 1.8 cm (5.3 compared to 7.1 cm) or 34% as compared to the coarser sand after 24 h of drainage and 1.6 cm or 31% after 48 h of drainage. In sand : peat mixtures, the finer sand mixtures retained between 1.8 and 2.6 cm more water than the corresponding coarser sand mixtures.

Increased water holding capacity is one of

the reasons peat is mixed with sand for sports turf areas; thus, we expected that sand : peat mixtures would retain more water than unamended sand. Sand : peat mixtures comprised of the coarser sand retained 2.4 to 4.2 cm more water than the unamended sand. For the mixtures composed of the finer sand, sand : peat mixtures held 3.4 to 4.4 cm more water than unamended sand after 24 or 48 h of drainage. For either sand, sand : reed-sedge peat mixtures held significantly more water than sand : sphagnum peat mixtures.

The sand : reed-sedge peat mixtures had twice the organic matter (Table 1), on a mass basis, than corresponding sand : sphagnum peat mixtures despite having identical volume mixing ratios. This difference in organic matter content may well have had a greater effect on water retention of mixtures than inherent differences between sphagnum and reed-sedge peats.

The location of water held in the profile is important since most turfgrass roots, especially on golf greens, will be in the upper portion of the root-zone soil mixture. Trends in water held in the upper 15 cm of the soil mixture layer were almost identical to trends in total water retained. Of the total water retained in the 30-cm soil mixture layer, 31% to 38% was held in the surface 15 cm for all mixtures.

In every soil mixture, a zone of increased water content just above the coarse sand and gravel layers was clearly evident (Fig. 1). In the unamended coarser sand, the zone of greatly increased water content rose ≈ 6 cm above the coarse sublayer. In the coarser sand : peat mixtures, the wet zone rose ≈ 12 cm above the sand layer. In the unamended finer sand, the zone was ≈ 9 to 12 cm thick, while in the finer sand : peat mixtures the wet zone extended 15 to 18 cm up from the very coarse sand layer.

Fig. 1. Volumetric water content in 3-cm increments of soil mixtures after 24 and 48 h of drainage. The 30-cm soil mixture layer was underlain by a 5-cm coarse sand layer that in turn was over a 10-cm gravel layer. Values shown are means of three replications (error bars are 1 SD).

Fig. 2. AFP of soil mixtures after 24 and 48 h of drainage. Values shown are means of three replications (error bars are 1 SD).

The zone of increased water retention was at or near saturation after 48 h of drainage in some cases.

The unamended coarser sand retained $\approx 10\%$ AFP in the lower, wet portion of the root-zone layer (Fig. 2). The coarser sand : sphagnum peat mixture had 3% to 7% AFP in the lower 9 cm after 24 h of drainage, but, for an unexplained reason, jumped to 13% to 18% after 48 h of drainage. This magnitude of increased drainage between 24 and 48 h exceeded that of any other mixture. The coarser sand : reed-sedge peat mixture drained to between 2% and 8% AFP, while the unamended finer sand drained to between 6% and 9% AFP in the lower 9 cm after 24 or 48 h of drainage. The finer sand : peat mixtures were clearly excessively wet in the lower portion of the root-zone mixture layer with $<5\%$ AFP in the lower 12 cm of the finer sand : sphagnum mixture and $<5\%$ AFP in the lower 18 cm of the finer sand : reed-sedge peat mixture.

The level of AFP at which root respiration and growth are affected is not simple to evaluate. Hillel (1982) suggests that results of these attempts have been baffling, with reported limiting values ranging from 5% to 20% and averaging around 10%. Hanks and Ashcroft (1976) and Marshall et al. (1996) use a general value of 10% AFP below which plant growth may be affected by low oxygen concentration, but note that it will certainly vary depending on some other factors.

Most turfgrass roots in a golf green or sports turf will be in the upper portion of the root-zone mixture even with adequate aeration throughout the layer. The surface 10 cm would likely be adequately aerated even with the conditions created with the finer sand : peat mixtures; however, where root growth throughout the surface layer is desired, excessively wet conditions lower in the root-zone mixture may pose a distinct restriction.

This experiment demonstrated the necessity of careful selection of root-zone soil mixtures when sports turf areas are built in a layered fashion with coarse sand and gravel underlying the root-zone mixture. The increased water retention in the root-zone soil mixture resulting from underlying coarse-

textured layers may lead to zones in the rooting area that remain at or near saturation for extended periods, reducing root growth and perhaps causing other problems associated with excessively wet soils.

We have demonstrated that sand and peat have critical effects on water retention. Sand and sand : peat root-zone mixtures composed primarily of sand particles between 0.25 and 1.0 mm in diameter had lower bulk densities, higher infiltration rates, lower water holding capacities, and higher AFP than mixtures containing principally particles between 0.10 and 0.50 mm in diameter. Sand : peat mixtures, as compared to unamended sand, had lower bulk densities after packing, higher water holding capacities, and lower AFP. Using a processed reed-sedge peat of small particle size in sand : reed-sedge peat mixtures had higher bulk densities, lower infiltration rates, higher water holding capacities, and lower AFP than sand : sphagnum peat mixtures.

In a 30-cm layer of root-zone mixture overlying very coarse sand and gravel layers, the coarser sand : peat mixtures and the unamended finer sand appeared borderline in terms of holding excessive amounts of water in the lower 9 cm of the layer. The lower 12 to 15 cm of the finer sand : peat mixtures retained excessive amounts of water and would result in poor conditions for turfgrass root growth.

When sand : peat mixtures over gravel layers are used in construction of sports turf areas, we recommend that the root-zone layer be at least 30 cm deep and, where 80 sand : 20 peat mixtures (v/v) are used, sand be predominantly of particles between 0.25 and 1.0 mm in diameter and that a reasonably fibrous peat, such as sphagnum, be used. This mixture likely will help prevent an excessively wet zone forming above the gravel layer and encroaching into the rooting area of the plants.

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