Understanding the Hydrology of Modern Putting Green Construction Methods

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Goals:

- Examine the effects of rootzone composition and putting green construction method on water drainage and redistribution within the profile.

- Examine the effects of rootzone composition, soil profile depth and degree of water perching on turf water use and irrigation management.

- Examine long-term changes in physical, biochemical and microbiological properties of the rootzone; and relate these changes to the long-term hydrologic behavior of modern putting green designs.

Cooperators:

Dr. Warren Dick
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The two most prevalent putting green construction specifications are the United States Golf Association (USGA) and the California (CA) green construction techniques. This research is directed toward a more complete understanding of how profile design, rootzone composition, green slope, drain spacing, and irrigation protocol impact the hydrology of these modern putting green construction methods.

This research program was initiated in the spring of 1996. The principal scheduled activity was the set-up and preliminary testing of an experiment to examine water infiltration and movement within USGA and CA putting green soil profiles. Additionally, each soil profile design contains either a high or low water permeability rootzone resulting if 4, soil profile/rootzone composition treatments for the overall experiment. Three replicate profiled were constructed for each treatment combination.

The unique feature of this experiment is the provision for variable slope adjustment in these experimental greens. As such, 12 experimental units were constructed with each containing a 4 by 24 ft section of each putting green treatment supported 1 ft above ground level. The soil profiles were contained within wooden boxes supported by a legged, metal framework and placed on a cement pad. Slope adjustment is accomplished by raising one end of each unit until the desired slope is attained. Additionally, simulated drainlines are built into each unit to allow for variable drain spacing of 10, 15, or 20 ft, and 15 soil moisture probes were installed at 3 depths and 5 distances along each unit for detailed monitoring of water movement within each profile. Finally, devices to deliver controlled rainfall and record drainline flow were designed and constructed. Penncross creeping bentgrass was established on each experimental green and, after grow-in, will be maintained as an actual putting green.

A preliminary experiment revealed that the 4, soil profile/rootzone composition treatments do indeed exhibit distance hydrologic behaviors. As expected, the low permeability mixes exhibited higher water contents than the high permeability mixes. There were also substantially higher water contents with depth and particularly at downslope locations with the greens set to 4% slope. Further, the measurement and control systems for this experiment were shown to perform within their design specifications. A preliminary statistical test conducted from the data of this experiment suggests that valid treatment comparisons will be achieved from the experimental protocol.

Finally, baseline analyses of the soil physical, chemical and microbiological properties of the soil profile rootzones are in progress. These observations will be combined with subsequent measurements to monitor changes that occur in these properties with time.

The principal investigator has formally committed 10% of his time to this research project. One graduate student has committed 100% effort for 6 months and a second student 50% effort for 3 months. Additionally, a technician has committed 50% of his time since the beginning of the project. Construction expenditures not supported by the USGA were conservatively estimated at $24,000 including measurement instrumentation. Donated labor was provided by University Physical Plant personnel; and donated materials included the rootzone mixes, irrigation equipment, and other miscellaneous items. To date, $2,500 in supply items have been purchased from the USGA budget.

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Progress Report
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The two most prevalent, modern putting green construction methods are the United States Golf Association (USGA) and the California (CA) green construction techniques. The principal differences between these construction methods are the presence of a gravel drainage blanket in the USGA design and a higher recommended rootzone permeability in the CA design. These differences will, at least in theory, yield different hydraulic behaviors of these two greens construction methods. The vertical and lateral pathways of water movement during profile drainage in the CA method occur exclusively in the rootzone sand layer. In the USGA system, vertical water movement occurs in the rootzone while lateral water movement occurs in the gravel drainage blanket. This would imply improved internal drainage in the USGA system. On the other hand, the higher permeability of the CA system rootzone may allow sufficiently rapid drainage even in the absence of the gravel drainage blanket.

Following complete profile drainage, the USGA design creates a perched water table extending into the rootzone while no such water table occurs in the CA system. Subsequently, this perched water table may act as a reservoir for water use by the turf. Thus, the USGA system should allow less frequent irrigation for adequate turf maintenance as compared with the CA design.

Our current understanding of these systems, however, ignores the natural contours of a putting green that may promote lateral water flow within the soil profile. In this case, water perching in a USGA profile may be reduced at upslope locations and rapid profile drainage may be accomplished without a gravel drainage blanket. There is also insufficient evidence for the need of the perched water table as a reservoir for turf use given currently employed irrigation practices. Finally, there is a need to document the long term biochemical, microbiological and physical property changes that occur in a putting green soil profile and to examine how these changes influence the hydrology of the overall profile design. This research will examine these issues by addressing the following objectives:

1) Examine the effects of rootzone composition and putting green construction method on water drainage and redistribution within the profile.

2) Examine the effects of rootzone composition, soil profile depth and degree of water perching on turf water use and irrigation management.

3) Examine long-term changes in physical, biochemical and microbiological properties of the rootzone; and relate these changes to the long-term hydrologic behavior of modern putting green designs.

Research Progress

This research program was initiated in the spring of 1996. The principal scheduled activity for the current funding period was the set-up and preliminary testing of the Objective 1 experimental units. The Objective 1 study employs two profile designs, a 2-tier USGA system and a CA system, each containing two contrasting rootzone mixtures. These 4 profile/rootzone treatments were replicated three times for a total of 12 experimental units. The following documents the construction, instrumentation and turf establishment in the experimental units. Figure 1 shows completed units and may serve as a useful reference to follow the construction details.

<u>Construction of Objective 1 Units</u> The experimental units consist of 4 by 24 ft wooden boxes supported by a legged, metal framework. The 4 by 24 ft, custom built framework consists of 2 by 4 inch channel stock having 1 by 2 inch cross supports every 16 inches. This framework is supported 12 inches off the ground using metal legs placed every 8 ft along the long dimension. A wooden box was placed on and is supported laterally by this metal framework. The box sides consist of nominal 2 inch lumber lined with 0.5 inch plywood. The box bottom was 0.5 inch plywood and rests on the metal frame and cross supports. Openings for placement of simulated drainline trenches were cut into the bottom plywood. The 6 inch wide by 8 inch deep simulated drainline trenches were fabricated from sheet metal and each contained an outlet in the center. For experimental units containing a USGA 2-tier profile, the sides of the wooden box was 16 inches whereas units containing a CA system profile were 12 inches. The drainline trenches (perpendicular to long axis) were constructed into each unit at 2, 12, 17 and 22 ft from the downslope end. Nominal 2 inch PVC drainpipes were connected to the outlet of each drainline trench with each fitted with a valve for selective closure.

The 12 experimental units were placed, in a randomized complete block design, on an 80 by 28 foot concrete pad poured to a 4% slope and located in an open area. Water and electrical service was trenched to the site and a commercial irrigation system (designed by an irrigation contractor) was laid out on the pad. The automatic irrigation system allows for separate irrigation control of each treatment block.

The two rootzone mixes were designed to bracket the current USGA particle size and physical property range with, for example, one exhibiting a saturated conductivity in the accelerated range and a higher air-filled porosity, and the other exhibiting a normal range conductivity and lower air-filled porosity. The protocol used for acquiring the experimental rootzone mixes closely followed recommended procedures for typical greens construction. A testing lab (N.W. Hummel & Co.) and a rootzone mix supplier (Kurtz Bros. Inc.) were contacted and agreed to participate in formulating the rootzone mixes. Candidate mix components were provided to the testing lab by the supplier. The testing lab created test mixes from these components and performed particle size and physical property measurements on these test mixes. The mix for each experimental rootzone that best matched my specified performance criteria was selected and the 'recipe' for this mix was subsequently provided to the supplier. The supplier repeated this specified formulation and returned a quality control sample to the testing lab. Upon approval by the testing lab and myself, the rootzone mix was shipped to our location.

Figure 1. The Objective 1 experimental units (12 total).

The recommended procedure for acquiring rootzone mixes appears straight forward on paper, but it was not as simple in practice and problems arose at virtually every step. These problems were, however, overcome and satisfactory rootzone mixes were acquired. The high permeability rootzone consists of a 9:1 sand:sphagnum peat blend and the low permeability rootzone consists of a 6:2:2 sand:biosolids compost:topsoil blend. Samples of both rootzone mixes were collected for initial physical, chemical and microbiological analysis. The results of these analyses are presented in Tables 1 to 4.

Table 1. Particle size analysis of rootzone mixes for Objective 1 experiments.

	Sand Particle Diameter (mm) % Retained					
Sample	Gravel 2 mm	V. Coarse 1 mm	Coarse 0.5 mm	Medium 0.25 mm	Fine 0.15 mm	V. Fine 0.05 mm
High Permeability	0.0	10.6	37.9	38.9	8.8	1.8
Low Permeability	0.4	2.6	17.0	58.9	12.9	3.0

The high permeability rootzone mix consisted of 98.0% sand, 1.2% silt and 0.8% clay. Additionally, most of the sand fraction was evenly split between coarse and medium particle diameters (Table 1). The low permeability mix consisted of 94.8% sand, 3.8% silt and 1.4% clay with a large portion of the sand particles having medium particle diameters (Table 1). Physical property analysis indicated that these rootzone mixes achieve our desired goal with the high permeability mix having a saturated conductivity in the accelerated range and the low permeability mix having a saturated conductivity in the normal range according to USGA specifications (Table 2).

Table 2. Physical properties of rootzone mixes for Objective 1 experiments.

Sample	Bulk Density g/cc	Ksat in/hr	Total Porosity %	Aeration Porosity %	Capillary Porosity %	Water Retention %
High Permeability	1.58	20.8	41.4	22.5	18.9	12.0
Low Permeability	1.45	12.6	44.4	21.0	23.4	16.1

Soil chemical analysis revealed that the mixes had a suitable pH's and that levels of available nutrients were generally higher in the low permeability mix containing biosolids compost and topsoil (Table 3).

Table 3. Soil chemical analysis of rootzone mixes for Objective 1 experiments.

Sample	pH	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	CEC
		-------------------	-------------------	-------------------	-------------------	lbs/Ac	-------------------	-------------------	-------------------	-------------------	meq/ 100g
High Permeability	7.6	10	68	5116	193	32	16	22	1.0	1.7	13.8
Low Permeability	7.1	200	182	2130	213	86	58	59	20.6	4.1	6.6

Analysis of the bacterial and fungal populations in the freshly received rootzone mixes revealed higher bacterial populations in the low permeability mix than the high permeability mix (Table 4). Both mixes had a relatively high number of fungal colony forming units (CFUs). Fungal counts for the low permeability mix are, however, most likely 10 to 100 fold greater than represented due to difficulty in distinguishing small fungal colonies from actinomycetes. Fungal counts are currently being repeated following a longer incubation period for both the low and high permeability mixes.

Table 4. Initial bacterial and fungal population densities in rootzone mixes for Objective 1 experiments.

Sample	Medium	Relative Population Density log CFU/g dry wt
High Permeability	King's Media B[1]	8.38
	0.1 Trypticase Soy[2]	8.55
	Acidified Potato Dextrose[3]	6.24
Low Permeability	King's Media B	10.16
	0.1 Trypticase Soy	10.42
	Acidified Potato Dextrose	6.11
$LSD_{0.05}$		0.28

[1] King's Media B used to enumerate fluorescent pseudomonades.
[2] 0.1 Trypticase Soy is a general media used to enumerate soil bacteria.
[3] Acidified Potato Dextrose media is used to enumerate fungi.

Separate gravel materials were required for each rootzone mix due to the different mix D_{85} values. These gravel materials were acquired and tested for conformity to USGA specifications prior to placement in the profile. The appropriate gravel material was placed to mounding in the drainline trench (containing rigid, perforated 4 inch PVC drainpipe) of the CA system units and also to a 4 inch depth in the USGA units. Subsequently, the appropriate rootzone mix was placed, wetted and firmed in each of the experimental units.

Instrumentation Following construction of the experimental profiles, buriable Time Domain Reflectometry (TDR) wave guides (Soil Moisture Equip. Co.) were horizontally inserted into the profile at 3 depths (3, 6 and 9 inches) and 5 locations (0, 5, 10, 15 and 20 ft from the downslope drainline trench) for a total of 15 positions per unit. Wave guides were inserted by cutting trenches (4 by 12 inch and 10 inch depth) into the soil profile and inserting each wave guide at the appropriate depth into the adjacent, undisturbed soil. The trenches were subsequently backfilled and the TDR cables fixed to the outer edge of the wooden boxes.

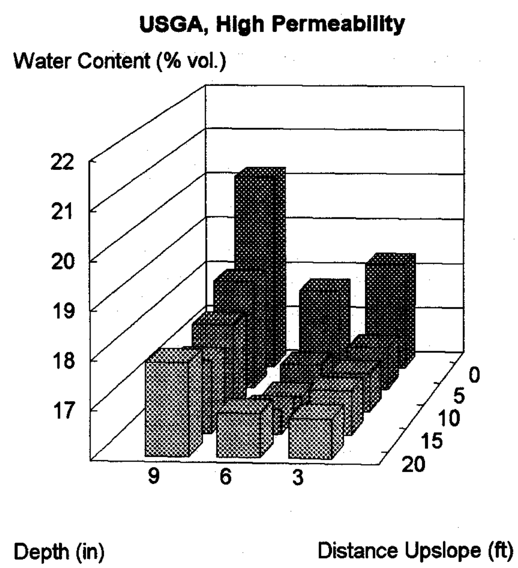
Turf Establishment A uniform application of starter fertilizer and a fungicide was incorporated into the upper 3 inches of each soil profile. Fertilizer was applied at 3 lbs N, 1.8 lbs P, and 2.4 lbs K per 1000 sq ft. A micronutrient fertilizer was also applied and the fungicide was granular 2% Subdue at 25 oz per 1000 sq ft. The profiles were subsequently seeded with Penncross creeping bentgrass at 2 lbs pls per 1000 sq ft. Seeding occurred on 28 July, 1996.

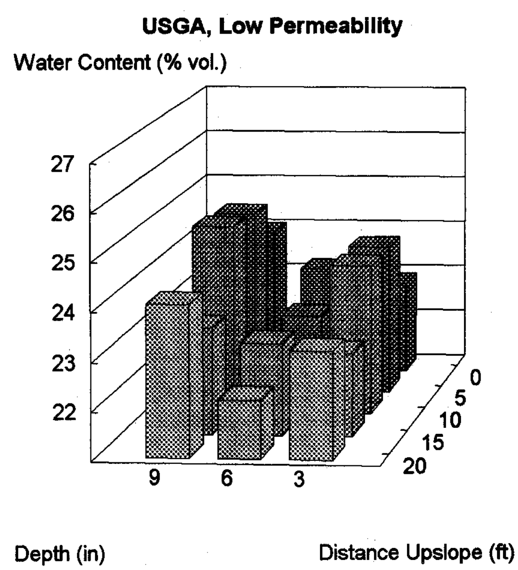
During the turf establishment period, efforts were directed to design and construction of the simulated rainfall devices and tipping bucket rain gauges. The simulated rainfall device employs a cam driven mechanism that rotates a boom which is centered along the long axis of an experimental unit at 42 inches above the turf surface. Fan shaped, large droplet spray nozzles are fixed to the boom every 40 inches. The shape of the rotating cam was designed to provide a constant rate passage of the droplet spray across a horizontal surface. The cam rotates at 6 rpm delivering 12 passes over the experimental unit per minute. The tipping bucket rain gauges consist of paired, triangular shaped pans that sequentially fill and empty. This tipping action triggers a simple electrical switch that is connected to the pulse counter of a datalogger (Campbell 21X). The tipping bucket rain gauge will collect outflow from the downslope drainline to monitor drainage outflow rate.

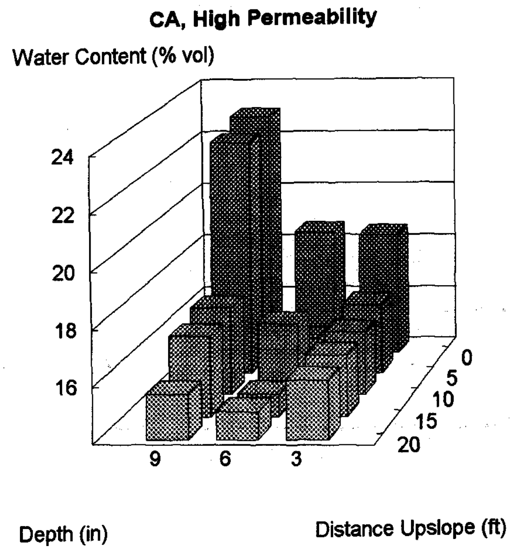
Review of Objective 1 Protocol This experimental set-up will be employed to monitor water infiltration, redistribution and drainage as influenced by green slope, drain spacing and rainfall rate. During an experimental run, one replicate of the 4 treatment units will be configured to a slope of 0, 2, or 4% and selected drainpipes will be closed yielding drain spacing of 10, 15, or 20 ft. Simulated rainfall at either 1, 3 or 5 in/h will be uniformly applied to each unit until steady outflow is observed. At this time, soil moisture and outflow measurements will commence and rainfall will be suspended. Automated soil moisture measurements will be accomplished by multiplexed connection of each TDR wave guide to a TRASE (Soil Moisture Equip. Co.) soil moisture measurement unit. Likewise, drainline outflow will be automatically recorded using a datalogger. Profile drainage and subsequent moisture redistribution will be monitored for up to 48 hours. This protocol will then be repeated for the second replicate.

Preliminary Results At present, only data from a preliminary experiment has been completed and analyzed. The purpose of this experiment was to test the soil moisture measurement system, assess the general drainage behavior of each treatment, and to estimate variability among the replicate units. The experimental units were configured to 4% slope and drain spacing of 10 ft. Subsequently, all units were evenly and thoroughly wetted using a combination of natural rainfall and irrigation. Soil moistures were collected after a rain free period of 48 hours.

Mean values of soil water content as a function of soil depth and distance upslope are shown in Figure 2 for the 4, soil profile/rootzone mix treatments. These results were encouraging in that the measurement system performed well and generally different behaviors were observed for each system. As expected, the low permeability mixes exhibited higher water contents than the high permeability mixes. There were also substantially higher water contents with depth and particularly at downslope locations. Surprisingly, lower water contents were occasionally observed at the 6 inch depth than the 3 inch depth. Finally, standard errors for each replicate measurement averaged 0.29% for the USGA-high permeability, 0.77% for the USGA-low permeability, 0.35% for the CA-high permeability, and 1.23% for the CA-low permeability treatments. These low standard errors suggest that soil moisture measurements that differ by only a few percent should yield statistically significant contrasts.







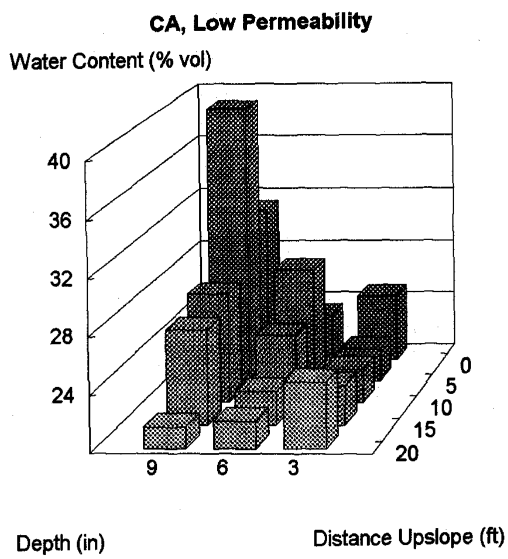


Figure 2. Mean soil water contents of the Objective 1 treatments as a function of soil depth and distance upslope.

Additionally, soil samples were collected from each experimental unit 10 weeks after turf emergence. These samples are currently being processed for soil physical, microbiological and biochemical analyses.

Research Plans

Objective 1 experiments will continue as long as weather permits this fall and will continue during the spring of 1997. Expected results include insight into the effects of rootzone mix composition, profile slope, and drain spacing on the drainage characteristics of a USGA and CA system putting green prior to play. This study will also address how the rootzone mix and profile slope interact in the maintenance of a perched water table in the early life of a putting green.

Simulated foot traffic will be applied to the Objective 1 units during the summer of 1997 and the water infiltration, redistribution and drainage experiments repeated in the fall of 1997.

Set-up of the Objective 2 experimental units will commence during the winter months of 1996-1997. As outlined in the research proposal, Objective 2 experiments will commence during the summer of 1997. Expected results include an examination of the effects of water perching, and soil profile depth on turf water use and irrigation management for various rootzone compositions.

Finally, we are currently conducting and will continue the rootzone mix characterizations in support of Objective 3 using destructive and non-destructive techniques.