sub-angular sands had the best combination of compaction resistance and strength.

Layers in Golf Green Construction

Sports Turf Research Institute

Dr. Stephen Baker

Start Date: 1996
Number of Years: 2
Total Funding: $28,778

Objectives:

1. *To examine particle migration from the rootzone layer into underlying gravels of increasing size in situations where no intermediate layer is present.*
2. *To assess the effects of different intermediate and drainage layers on moisture retention in the rootzone layer.*
3. *To review the particle size criteria for the selection of intermediate layer and drainage layer materials.*

Particle Migration is being examined for two contrasting rootzone materials placed directly over ten drainage layer gravels of varying sizes. The two rootzones are an 85:15 mix of medium sand and sphagnum peat and a 70:30 mix of medium-coarse sand and peat. Five of the gravels are rounded and the other five are angular. The D_{15} size values range from 2.2 mm to 5.6 mm. Gravel sizes were selected so that, in theory, no migration would occur from the rootzone into the gravel for the finer gravels but the risk of particle migration into the coarser gravels was high. Each profile is receiving 3000 mm of simulated rainfall before particle migration is examined.

A technique was developed to examine whether migration has occurred at the interface of the rootzone layer and the gravel (Figure 3). The profile is stabilized using plaster of Paris. This is then impregnated with an araldite resin containing fluorescent dye. When the resin has hardened, the profile can be sectioned and photographed under ultra-violet light. This will enable examination of pore-space blockage within the gravel due to particle migration from the rootzone.

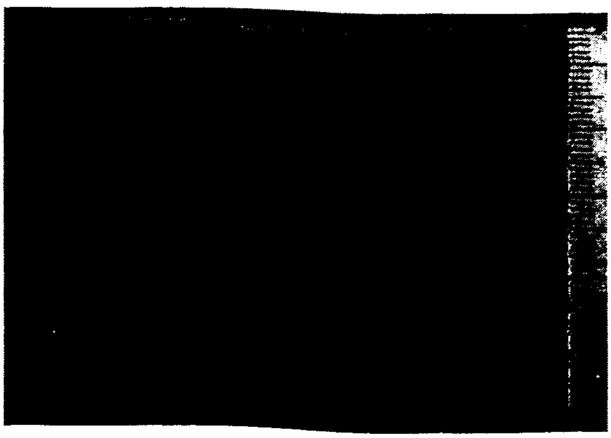

Figure 3. Cross section of intermediate sand layer above the gravel layer observed under UV light.

Moisture Profiles. The vertical distribution of moisture within the profiles discussed above is being measured after 48 hours of gravitational drainage to examine whether variations in the in type of gravel influence moisture retention in the profile.

In a separate study, the influence of particle size of the intermediate layers on moisture retention within an 80:20 sand/peat rootzone has been examined. The underlying gravel was predominantly a 6 to 9 mm material while the intermediate layer was based on 1 to 4 mm grit but with increasing proportions of medium (0.25-0.5 mm) and coarse sand (0.5-1.0 mm). Moisture profiles were assessed after saturation followed by 48 hours gravitational drainage.

Increasing proportions of coarse and medium-coarse sand had significant effects on the moisture content of the intermediate layer. For example volumetric moisture content increased from 7.5 percent when the 1 to 4 mm. grit included no sand to 18.4 percent when 50 percent coarse sand was added to the grit. However, no strong relationships were found between the composition of the intermediate layer and moisture retention with the rootzone. These data suggest that it should be possible to increase the proportion of material between 0.25 mm and 1 mm in the intermediate layer without a significant reduction of water retention in the rootzone. However, the work on moisture profiles directly over a gravel base must be completed before firm recommendations are made.

Understanding the Hydrology of Modern Putting Green Construction Methods

The Ohio State University - OARDC

Dr. Edward McCoy

Start Date: 1996
Number of Years: 5
Total Funding: $100,000 (co-funded with the GCSAA)

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 compostition, soil 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.*

The overall program investigates the influence of green construction method on hydrologic processes including water infiltration, redistribution within the rootzone, drainage, and uptake by the turf. 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 root zone permeability in the modified CA design. The one modification in the CA greens for these experiments was the addition of organic matter (sphagnum peat) to the rootzone mixture. However, this is commonly done throughout the United States where these greens are constructed.

Phase I. Earlier reported research on these systems examined water drainage and redistribution as influenced by root zone composition and green slope. The results of this study showed that putting green profile design, root zone permeability, and slope all yielded distinct hydrologic behaviors. Given equal root zone permeability, the experimental USGA greens yielded a more rapid drainage. Indeed, even a rainfall rate of about 4.5 inches per hour failed to overwhelm drainage of the USGA profiles as evidenced by equivalent drainage rates for both the low and high permeability root zones. Further, this same rainfall rate exceeded the drainage capacity of the modified CA green containing a rootzone mix initially tested to have a permeability of 20 inches per hour. For equivalent drainage performance, therefore, it seems that a modified CA style green would need a root zone mix permeability at least 20 inches hour greater than a USGA green.

Drainage rate represents an intensity factor. The capacity factor of the drainage process is the completeness of excess water removal from the root zone. Here, it is commonly thought that a USGA green would be less completely drained than a modified CA green. Our results showed that for equivalent root zone mix permeability the USGA green was drier after 48 hours (interpreted as more completely drained) than a modified CA green. This appears to be principally due to the need for water to move laterally through the root zone in a modified CA green before reaching a drain line. Again, for more complete drainage, a modified CA green would appear to need a higher root zone permeability. Nearly equal soil moistures were found after 48 hours drainage in the modified CA high permeability profile and the USGA low permeability profile.

All greens are sloped somewhat. This contouring clearly has an effect on water redistribution following rainfall. Prior to this study we believed that the perched water table in a sloped, USGA green would lead to strong lateral movement of water to down slope locations. We did not believe this would occur largely in a modified CA green. Again, our results showed our prior beliefs to be somewhat incorrect. While lateral water movement was observed in sloped USGA greens, it was also observed in modified CA greens. Thus, for equal rootzone permeability, there was a much greater lateral difference in water contents after 48 hours drainage in the modified CA greens than in the USGA greens.

The current findings of our Phase I research (as summarized above) are incomplete without a physical characterization of the root zones for the respective experimental greens. Thus, we have conducted lab and field measurements of root zone physical properties from *fresh* mixes and from the Phase I root zones on a yearly basis. We will continue these measurements for the 5-year duration of the overall project.

Table 1. Mean ponded infiltration rates and soil water contents with depth as influenced by putting green soil profile and root zone mix composition.

Profile	Root Zone	Infiltration Rate (40 mm head)	Water Content 3 in depth	Water Content 6 in depth	Water Content 9 in depth
		cm min^{-1}	m^{3}m^{-3}	m^{3}m^{-3}	m^{3}m^{-3}
USGA	High Perm.	1.91	0.47	0.46	0.44
	Low Perm.	1.20	0.43	0.43	0.41
California	High Perm.	1.31	0.44	0.40	0.44
	Low Perm.	0.96	0.45	0.41	0.41
<u>Analysis of Variance</u>					
Profile		*	NS	**	NS
Root Zone		**	**	*	NS
Profile x Root Zone		NS	**	*	NS
LSD (0.05)		0.41	0.013	0.013	0.06

*, **, *** indicates significance at $p<0.05$, 0.01 and 0.001 respectively.
LDS (0.05) given for the highest order interaction.

Ponded infiltration rates measured 20 months after turf establishment (Table 1) yielded some surprising results but were consistent with our observations reported in November, 1997. While we expected and observed greater infiltration rates from the high-permeability root zone, we also observed greater infiltration rates from the USGA profile than in the modified CA profile. Apparently, the presence of the gravel drainage blanket below the root zone in the USGA profile allowed for more rapid water infiltration regardless of the rootzone mix composition. This behavior was inferred in our previous study where a reduction in total drainage from the modified CA profile was associated with visually observed runoff that was not apparent for the USGA profile. Thus, soil profile features at 12 inches depth have an influence of water entering the soil surface in modern putting green designs.

In addition, the Phase I research showed lateral patterns of root zone moisture after 48 hours drainage. These patterns were influenced by drain line spacing in modified CA greens and slope in both modified CA and USGA greens. The question, therefore, arose whether turf drought symptoms would be observed with lateral position across these greens if further irrigation was withheld. Consequently, we conducted an initial replication of a dry-down study on the Phase I experimental units to help address this concern.

We anticipated an earlier onset of drought stress in the high permeability rootzones than in the low permeability rootzones. We also anticipated earlier drought over drain lines in the modified CA green with no slope, and at further distances up slope for both green systems at 4 percent slope. The strongest realization of these expectations was the response to slope in the high permeability modified CA and USGA greens. These greens at 10 days contained from 6 to 7 percent surface soil moisture at up slope locations and from 15 to 16 percent moisture at extreme down slope locations. This gradient in soil moisture yielded progressively increased stress symptoms from the down slope to the up slope locations. This was confirmed by our clipping yield measurements where fewer clippings were collected at up slope locations than down slope locations. Some of the more subtle turf responses to stress during this dry down study (if they exist) will require further data analysis before they are revealed.

Finally, one caveat of our Phase I results to date is that these greens were just one year old and had not experienced foot traffic. During this past year, we have applied simulated foot traffic to the greens by using a weighted roller. The roller is 4 feet in length, 8 inches in diameter and has a weight of about 325 lbs. The 'rolling factor' for this roller is about 1.2, which we estimate to simulate the heel pressure of an average human. Consequently, the water drainage and redistribution study conducted in the fall of 1997 will be repeated in the spring of 1999.

Phase II Progress. We have recently completed construction and established turf on an additional experiment to assess turf water use as influenced by root zone depth, root zone composition, and water perching in a USGA profile. The study employs six root zone mixes and two root zone depths constructed as a 2-tier USGA soil profile. Two of the root zones are 100 percent sand where the sands are relatively coarse and fine as based on USGA specifications. Two root zones are sand:sphagnum peat blends using the coarse and fine sand materials, and the final two root zones are sand:soil:peat blends again using the coarse and fine sands. Each root zone is placed in a 2-tier USGA profile with root zone depths of 9 or 12 inches. Each root zone mix and profile depth treatment combination is replicated three times for a total of 36 experimental greens.

To study turf water use, a complete accounting must be made of all water inputs and outputs from the root zone. For this reason, the greens soil profile is constructed within 6-ft diameter non-weighing lysimeters where drainage from individual greens is collected in an adjacent service pit. Additionally, TDR probes for soil moisture measurements are located at 3 and 6 inches depth for the 9-inch root zone and 3, 6 and 9 inches depth for the 12 inch profile. Use of the TDR probes will allow measurement of water loss from the turf by evapotranspiration. Water for the entire area is provided by an overhead irrigation system. The greens were seeded to Penncross creeping bentgrass in the spring of 1998.

Bacterial Populations and Diversity withing New USGA Putting Greens

University of Florida
Dr. M. Elliott

Auburn University
Dr. E. Guertal

Clemson Universtiy
Dr. H. Skipper

Start Date: 1996
Number of Years: 5
Total Funding: $66,667

Objectives:

1. *Determine bacterial populations associated with putting green root-zone mix materials.*
2. *Determine bacterial populations of the root-zone mixes before and after fumigation.*
3. *Compare rhizosphere bacterial populations on two different turfgrasses, bentgrass and bermudagrass.*
4. *Compare rhizosphere bacterial populations of bentgrass in two different locations, Alabama and South Carolina.*
5. *Compare rhizosphere bacterial populations of bermudagrass in two differrent locations, southern Florida and northern Florida.*
6. *Compare thatch development, rooting and bacterial population of bentgrass in relation to rootzone mix and nitrogen fertilization.*
7. *Compare soil and rhizosphere bacterial populations of root-zone mixes containing various clay sources.*
8. *Document rhizosphere bacterial population dynamics on bentgrass and bermudagrass over a four year time period.*