Part 2 of 2

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Computer Simulation Tracks Water Flow in Greens

Root zones of USGA, California greens connect directly to subsurface system for better drainage

By Ed McCoy and Kevin McCoy

In the December issue, we reviewed the need for a more accurate method for evaluating water flow in the three common types of greens: USGA (United States Golf Association), California and push-up. This month, we look at the results from the simulations.

Putting green soil profiles are classified into three general categories: USGA, California and push-up style greens. The USGA and California profiles are purposely constructed with each documented by written guidelines (USGA Green Section Staff, 1993; Davis et al., 1990). Push-up green soil profiles, on the other hand, have evolved from decades of sand topdressing applied to native soil. Whereas each has a sandy surface layer, or root zone, the thickness of this layer and the type of material underlying the sandy root-zone varies for each particular category.

The USGA green

The upper surface of the perched water zone occurs at the interface between green and blue or at water contents of about 27 percent by volume. This perched water, however, accumulates only to a limited extent in a USGA green so that the continued rainfall (from 3.5 to five hours) simply displaces an equivalent volume of water into the gravel layer. This implies that if the 1-inch per-hectare rain rate were to continue indefinitely, there would be no further accumulation of water within the soil profile, and an equivalent volume of water would just as rapidly be drained from the soil.

Water flow through the gravel starting at 3.5 hours is evident by the large water content values within the gravel layer just above the interface with the subgrade. This distribution of water within the gravel layer reaches its maximum extent at four hours with the characteristic pattern of lower water contents adjacent to the drainage trenches and (within the flat reaches) higher water contents in between. This pattern remains stationary during the final hour of rain indicating a steady rate of water flow from the gravel into the drain. Finally, during the rain period, the subgrade transitions from very wet to nearly saturated.

Although there is a slight decline in root zone water contents the hour following the rain, the results clearly show the establishment of a uniformly thick perched water layer from hours six to 12. This perched water layer appears to be only about 3 inches thick, characteristic of the lesser water retaining root zone employed in this simulation. If the simulation were to have used a root zone mix with smaller air-filled porosity values and greater capillary porosity values, then this would have resulted in a thicker perched water layer.

The uniformity of water perching across the green is, however, rather short-lived as down slope, lateral water flow in the more steeply sloped sections removes the perched water from the crest of these slopes. This becomes apparent at 24 hours by lower water contents above the root zone/gravel interface at the crest of the terrace face and (to a lesser degree) at the high point of the green and the crest of the false front. Down slope lateral water flow in sloped, USGA greens has been experimentally observed by both Prettyman and McCoy (2003a) and Frank et al. (2005).

After 24 hours, lateral flow has substantially slowed so that for the remaining hours of the simulation (from 24 to 162 hours) the root zone simply becomes progressively drier due to water uptake by the turf. It is interesting to observe during this period that the organic-enriched layer maintains greater water contents than the adjacent portion of the lower root zone. This is because the soil of the organic-enriched layer has greater water-holding properties than the lower root-zone layer.

Also, the progression of drying appears to be independent of root-zone depth. This is interesting in that water uptake is shown to occur in the 6- to 12-inch depth increment even though roots were not present below 6 inches. Seemingly the water retained at these deeper depths was adequately "wicked" nearer the surface and taken up by the roots. Consequently, perched water occurring from 9- to 12-inches deep can apparently serves as a reservoir for subsequent turf uptake in these systems.

Viewing the progression of drying across the green, however, shows more intense root-zone drying in regions of the green where the perched water was removed at 24 hours. Thus, the crest of the terrace slope, the high point of the green, and the crest of the false front all show more extreme drying throughout the root zone than other areas of the green. This is consistent with experimental observation of

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putting green slope effects on root-zone water content by Prettyman and McCoy (2003b) and Frank et al. (2005).

The California green

Early in the simulation, as with the USGA green, water infiltration results in the formation of perched water; in this case occurring above the root zone/subgrade interface. Unlike the USGA green, however, continued rain results in the perched water zone progressively (from three to five hours) approaching the soil surface till at the end of the rain the soil is nearly saturated to the surface. This progressive wetting of the root zone, however, does not occur uniformly across the green but mostly forms a pattern relative to the gravel-filled drainage trenches. In this case, water perching approaches the green surface midway between the drainage trenches yet remains deeper over the trench. A lateral pattern of water contents coincident with drainage trenches in a California-style green was also observed experimentally by Prettyman and McCoy (2003a). This pattern forms because a California green lacks a gravel layer underlying the root zone so that water must travel laterally rather long distances through the root zone before entering a drainage trench.

Following the rain, however, the zone of perched water recedes rapidly at first and then more slowly so that by 30 hours, the drain trench-induced pattern has disappeared and the perched water zone has a thickness of about 3 inches distributed somewhat uniformly across the green. The exception to this is the absence of perching at the crest of the terrace face and a 5-inch-thick perched water zone at the base of the terrace face.

For the remaining hours of the simulation (from 30 to 162 hours) the root zone simply becomes progressively drier due to water uptake by the turf. During this period, the dynamics of water flow in the California green is similar to that seen in the USGA green. The principal difference between these simulations is that the upper 6 inches of the California green is much drier for the same time slice than the USGA green. This is due to the smaller capillary porosity values and reduced water retention of the California root zone sand as compared with the USGA root-zone mix.

Drainage in the California green began 3.1 hours into the simulation and achieved its maximum rate of 28.3 cubic inches per hectare just as the rain ended. The drainage rate subsequently declined, rapidly at first and then more slowly. The California green required 31 hours before the drainage rate had slowed to a rate two orders of magnitude less than its peak. In the California green, the maximum drainage rate was about 60 percent of the rainfall rate, implying that had this rain rate continued indefinitely, water would have ponded on the green. The slower maximum drainage rate in the California green versus the USGA green is in agreement with the measurements of Prettyman and McCoy (2002).

The Push-up green

Water infiltration into the push-up green and the interruption of flow at the root zone/clay loam interface resulted in a virtually saturated soil profile when the rain ended at hour five. This situation remained virtually unchanged until hour 24 when water contents declined to the 25 percent to 35 percent range at the crest of the terrace face. It was not until hour 42, however, before most of the remaining areas of the root zone followed suit, opening up air-filled pore space for adequate soil aeration. The exception was the base of the terrace face and low point of the green where the soil remained wet. This overall result is substantially different from the USGA and California observations and is due to the 8-inch thick layer of fine textured native soil between the base of the root zone and the drainage trench.

This disconnect between the sandy root zone and the drainage system results in long-lived water accumulation following the rain. It is also important to note that this water saturation occurred with just 1 inch of rainfall.

After 68 hours, all regions of the surface 4 inches deep had dropped below a water content of 35 percent, opening air filled porosity for adequate gas exchange. This led to a laterally uniform drying of this layer throughout the remainder of the simulation. At the end of the simulation, water contents were greater across the surface of the push-up green than the USGA or California greens because of the increased water retention of the push-up green root-zone layers.

Drainage rates were roughly similar for the USGA and California greens, but drainage behavior in the push-up green was quite different from the others. Drainage in this green began at 14 hours, well after the end of the rain; and it peaked at a rate of 0.064 cubic inches per hectare at 35 hours. Because no drainage occurred during the rain event, it is inevitable that surface ponding would occur if this 0.25-inch-per-hectare rain had continued. This demonstrates how a relatively impermeable fine-textured soil can be a disconnect between rainfall and drainage in push-up greens.

Finally, the decline in drainage rate following the peak in this push-up green was gradual; unlike that seen in the USGA and California greens.

Conclusions

Throughout the seven days of this simulation, 70 percent, 63 percent and 9 percent of the total rainfall drained from the USGA, California and push-up greens, respectively. Thus, even though the amount of rainfall occurring on the push-up green was 25 percent of the others, a disproportionate small

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fraction of the rainfall found its way to the drainage trenches in the push-up green.

Cumulative evapotranspiration during the seven-day simulation was 27 percent in both the USGA and California greens as contrasted with 106 percent in the push-up green. The reason why evapotranspiration in the push-up green exceeded 100 percent was because some water initially present in the soil profile was used in evapotranspiration over the seven days. These facts, together with the other simulation results, emphasize that water flow in USGA or California greens are relatively similar when compared to a push-up green. This is principally because both USGA and California greens employ deep (12 inch), sandy root zones that establish a direct connection with the subsurface drainage system and displace layer interfaces well below the ground surface.

Differences in water flow that did occur between the USGA and California greens included the progressively deepening pattern of water perching during rain in the California green when, at the same time, water perching thickness was self-limited in the USGA green. Associated with this is the slower maximum drainage rate in the California green. Another difference was that the California green showed an earlier onset of drought stress than the USGA green.

These differences are principally due to the presence of a gravel drainage layer in the USGA green and the lesser water holding capacity of the California green root zone. Yet, both systems perched water that in both cases was short-lived at the crest of the steeper slopes. Further, perched water that was retained in the root zone was taken up by the turf in both systems even though rooting did not extend into this zone. Consequently, the first onset of drought stress in both cases was localized to the crest of the terrace face and, to a lesser degree, the high point of the green and the crest of the false front.

Finally, although there is substantial evidence that the simulations accurately depict water flow in these greens, it is important to remember that the greens were subject to extreme environmental conditions and that the simulations used a root zone with emphasized transmission attributes.

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