UNDERSTANDING WATER MOVEMENT IN A SLOPING GREEN

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INTRODUCTION

The United States Golf Association (USGA) introduced guidelines for constructing putting greens over 30 years ago and since then the USGA green has become the standard for golf course putting greens. The concept behind the USGA recommendations for putting green construction is to build a green that provides a measure of resistance to compaction in the rooting zone and drains quickly to an optimum soil moisture level. If greens lacked slopes there is little doubt that most, if not all, USGA greens would perform well. However with the slopes present on putting greens today, the USGA greens do not always perform ideally. Two problems that have commonly been encountered on greens are "Localized Dry Spot" (LDS) and "Black Layer". These problems are primarily associated with extremes in soil moisture in the rootzone of the green (Wilkinson and Miller, 1978; Tucker et al., 1990; Cullimore et al., 1990; Berndt and Vargas, 1992).

Specifications for a USGA putting green require that the sandy rootzone mixture be placed at a uniform depth of 30 cm (12"), across the entire surface of the green. However, the uniform rootzone mix depth does not account for the lateral flow of water in a sloping rootzone. Lateral flow occurs in sloping soil profiles when gravitational and surface tension forces acting on the water become larger than the attraction of water to the soil. This lateral flow causes lower water contents in high areas of the putting green resulting in dry soil conditions and susceptibility to LDS. Water flows laterally to the lower parts of the green causing higher water contents closer to the surface in the same green. This is the location where Black Layer most frequently occurs.

Research was initiated in 1998 at the Hancock Turfgrass Research Center to investigate whether or not altering the rootzone depth, decreasing it in high areas and increasing it in low areas, will increase the water content near the soil surface in high areas and decrease the water content of the rootzone mix in low areas.

MATERIALS AND METHODS

In 1998, a 950 m^2 (10,000 ft^2) research putting green was constructed at the Hancock Turfgrass Research Center at Michigan State University. The entire putting green is subdivided into 12 sloping plots. The profile of the green (from North to South) consists of a 2.3 m (8') long flat portion (toeslope North), followed by a seven percent 5.3 m (17.3') long slope (backslope North) to the summit, followed by a more gradual three percent 12.2 m (40') long downward slope (backslope South), followed by a final 4.5 m (14.7') long flat portion (toeslope South) (Figure 1). Barriers in the form of particle board dividing walls and PVC liners were placed along the length of each plot to prevent lateral movement of water between plots. Each plot received one of three rootzone mixes; sand/peat, sand/soil, or straight sand. Three plots (one of each rootzone type) have a rootzone mix with a uniform 30 cm (12") depth (standard USGA type) and three have a rootzone mix depth varying from 20 cm (8") at higher elevations to 40 cm (16") at lower elevations (modified USGA type). Drainage tiles were placed in trenches at strategic locations across the plots: at the extreme ends of each plot as well as at the end of each slope, and in the middle of the backslope of the 3% slope (Figure 1). The trenches were filled with gravel to cover the tiles and each tile was connected to a solid pipe that discharges at the lower end of each slope to a rain tipping bucket. A series of 120 Time Domain Reflectometry (TDR) probes and cables were buried in the soil to measure soil moisture in 10 cm (4") increments at several locations in every plot. The plots are arranged in a two factor complete randomized split-block design and are replicated twice. A Rainbird irrigation system was installed to provide uniform irrigation coverage for the entire green. The green was seeded with creeping bentgrass (*Agrostis palustris*) cultivar 'L-93' in June of 1998.

In 2001, data were collected on soil moisture, leaf surface temperature, turfgrass quality and color, and quantity of drainage water from various regions of the green. Turfgrass quality, color, and leaf surface temperatures were taken from five locations per green (toeslope North, backslope North, summit, backslope South, and toeslope South). Soil moisture readings were collected for four different 'dry down cycles' during the summer using a TRIME portable TDR unit for the 0 to 10 cm depth. A TDR100 and a series of multiplexers were used to measure soil moisture with the permanently installed probes at depths of 10-20 cm, 20-30 cm, and 30-40 cm. Soil moisture measurements were taken in the Northfacing toeslope (TDR Location 1), summit (TDR Location 2), and at two locations in the Southfacing toeslope (TDR Locations 3 and 4) (Figure 1). In 2001, 24 rain tipping buckets were installed on the north side of the green. This installation complemented the 36 rain tipping buckets already in place on the south end of the green. It is possible now to quantify all of the water draining from the green (Figure 1). Data from the rain tipping buckets were collected throughout 2001 and data are currently being analyzed to determine water drainage patterns from the green.

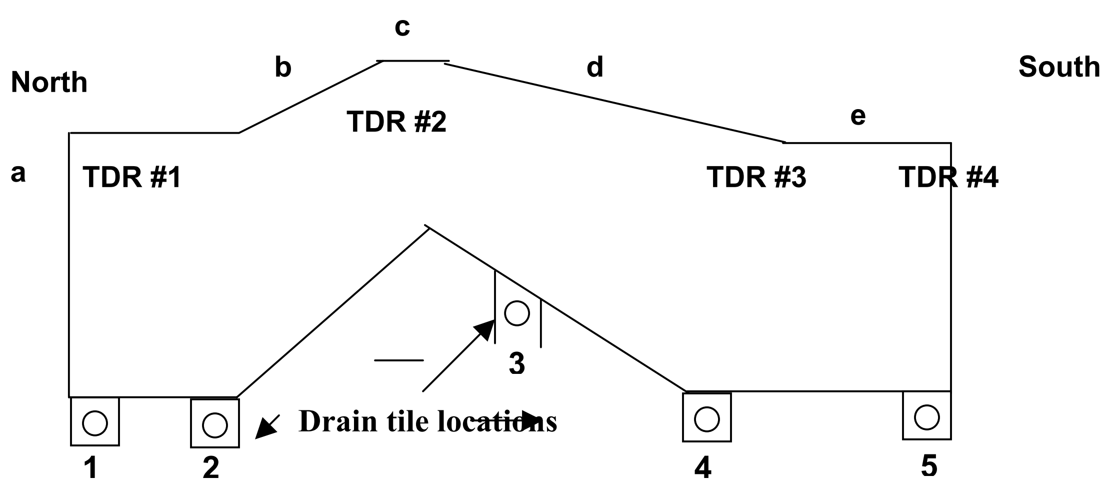

Figure 1. Cross section through plots with variable rootzone depth and different locations for measurements: (a) toeslope North, (b) backslope North, (c) summit, (d) backslope South, and (e) toeslope South.

RESULTS AND DISCUSSION

There were no consistently significant differences observed in quality, color, or leaf surface temperatures among the treatments in 2001. At several sampling times, there were location x construction type x rootzone mix interactions for turfgrass quality but analysis of the three way interaction revealed no important differences among the treatments. At several sampling times, the 100% sand rootzone greens color and quality ratings were significantly lower than the other two rootzone mixes.

The abundant amount of sunshine and the use of a mylar wind screen improved the reliability of the leaf surface temperature readings taken in 2001. However as in 2000, there were no significant differences in leaf surface temperatures among the treatments.

Soil Moisture

During the summer of 2001, there were four different 'dry down' cycles during which volumetric soil moisture measurements were taken using TDR probes. Data were analyzed separately by depth for the 0-10 and 10-20 cm depths. For the purpose of this report we will report only on the data in the 0-10 cm depth. Since the 20-30 and 30-40 cm depths are not present for both construction methods at all locations on the green, statistical comparisons of these depths was not conducted. The location x construction type interaction was significant throughout the dry down cycles. The location x rootzone mix interaction was significant at certain sampling dates but this interaction provides no information with respect to the effects of a variable depth rootzone mix on soil moisture relationships.

Location x Construction Type Interaction 0-10 cm Depth

Volumetric soil moisture content data for Days 1 and 4 of the three dry down cycles in 2001 are presented in Tables 1 and 2, respectively. At the beginning of a dry down cycle, when the rootzone is near field capacity, the location x construction type interaction was only significant on June 7. The differences in volumetric water content measurements on June 7 were relatively small (Table 1). Only at TDR Location 3 was there a difference between construction types, with the soil moisture content higher in the standard USGA construction type. For the other two dry down cycles there were no differences in soil moisture content between construction types or among locations on the first day of the dry down cycle.

Table 1. Volumetric soil moisture content for the location x construction type interaction at the 0-10 cm depth at the initiation of dry down cycles (Day #1) in 2001.

		TDR Location			
Date	**Construction Type**	**1**	**2**	**3**	**4**
June 7	Modified	24.9 AB†a‡	26.4 Aa	22.8 Bb	22.6 Ba
	Standard	27.6 Aa	24.2 Ba	26.7 ABa	24.4 ABa
June 25	Modified	28.0*	28.2	25.7	25.0
	Standard	29.2	27.6	26.9	25.2
July 16	Modified	25.2*	25.2	24.3	24.0
	Standard	27.1	24.1	26.3	25.1

†Means in a row followed by the same capital letter are not significantly different according to Fischer's protected LSD ($p = 0.05$).

‡ Means in a column followed by the same small case letter are not significantly different according to Fischer's protected LSD ($p = 0.05$).

*Data are not significantly different at $p = 0.05$.

At the end of the dry down cycles, Day #4, the construction type x location interaction was significant at all sampling times in 2001. Within the modified construction type there were no differences in soil moisture content among locations, indicating that the modified USGA construction type had uniform soil moisture across the entire slope of the green (Table 2). Across the slope of the standard USGA construction type green, volumetric soil moisture content values were lower at the peak of the slope, TDR Location 2, at all sampling times.

Comparisons of soil moisture content between construction types reveal that the modified USGA construction type had lower volumetric soil moisture content values at TDR Locations 1, 3, and 4 at all sampling times (Table 2). Additionally, the modified USGA construction type had the highest soil moisture content at the peak of the slope, TDR Location 2, for the June 10 sampling date.

Table 2. Volumetric soil moisture content for the location x construction type interaction at the 0-10 cm depth on the final day of dry down cycles (day #4) in 2001.

Date	Construction Type	TDR Location			
		1	2	3	4
June 10	Modified	15.7 A[†]b[‡]	15.9 Aa	12.6 Ab	13.6 Ab
	Standard	23.5 Aa	12.0 Bb	21.6 Aa	20.7 Aa
June 28	Modified	16.1 Ab	16.2 Aa	12.9 Ab	13.0 Ab
	Standard	20.7 Aa	13.0 Ba	20.4 Aa	19.2 Aa
July 19	Modified	18.1 Ab	19.0 Aa	18.1 Ab	16.5 Ab
	Standard	26.2 Aa	15.5 Ca	23.5 ABa	21.6 Ba

[†]Means in a row followed by the same capital letter are not significantly different according to Fischer's protected LSD ($p = 0.05$).
[‡]Means in a column followed by the same small case letter are not significantly different according to Fischer's protected LSD ($p = 0.05$).

Soil moisture content measurements from two dates in 2000 are presented in Table 3. The results from 2001 confirm our initial year of data collection in 2000 and indicate that the modified USGA construction type had lower volumetric soil moisture content than the standard USGA construction type at TDR Locations 1, 3, and 4. Although the differences were not statistically significant at this time, volumetric soil moisture content was greater at the peak of the slope, TDR Location 2, for the modified USGA construction type. The results confirm our hypothesis that altering the rootzone depth will decrease moisture content in lower regions and increase moisture content on elevated areas of greens.

Table 3. Volumetric soil moisture content for the location x construction type interaction at the 0-10 cm depth at the initiation (Day #1) and conclusion (Day #4) of dry down cycles in 2000.

Date	Construction Type	TDR Location			
		1	2	3	4
Aug.31 (Day #1)	Modified	17.5 B†a‡	20.8 Aa	16.2 Ba	17.6 Aa
	Standard	24.2 Aa	17.5 Ab	23.4 Aa	22.5 Aab
Sept. 3 (Day #4)	Modified	14.1 Ba	14.5 Aa	14.8 Ba	13.6 Ba
	Standard	21.2 Aa	11.3 Ab	20.8 Aa	19.1 Aa

†Means in a row followed by the same capital letter are not significantly different according to Fischer's protected LSD (p = 0.05).
‡Means in a column followed by the same small case letter are not significantly different according to Fischer's protected LSD (p = 0.05).

CONCLUSIONS

The results from 2000 and 2001confirm our hypothesis that altering the rootzone depth decreases soil moisture content near the putting green surface in lower regions of the green and increases soil moisture content near the putting green surface in higher areas of greens.

FUTURE DIRECTIONS FOR 2002

Research will continue to investigate soil moisture content using TDR probes throughout 2002. In addition, the installation of all rain tipping buckets in 2001 will enable us to continue to monitor drainage from the entire green to facilitate the formulation of water balance equations for the greens. The installation of the north side rain tipping buckets makes it is possible to quantify the total amount of drainage from each individual plot. The total amount of drainage is an important component in the water balance equation:

$$Pg = Et + dS + Ld$$

Where Pg is gross precipitation, Et is evapotranspiration, dS is the change in soil moisture, and Ld is total drainage. A balanced equation for an entire plot will lead to further division into subplots. The division into balanced subplots will lead to a better understanding of lateral flow within each soil profile. Determining the water balance from each green should enable us to identify the degree of lateral water flow occurring in the different rootzone mixes and construction types.

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