Managing Soil Moisture on Golf Greens Using a Portable Wave Reflectometer.

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Paper presented at the 28th Annual Irrigation Show
San Diego, CA
December 9-11, 2007

Abstract

The agronomic needs of grass and the demands of the contemporary golfer pose many challenges to managing irrigation on golf greens. The turf must be kept as dry and firm as possible without allowing it to die. Greens have a high degree of spatial variability, including hot spots that can rapidly become critically low in available water. Currently, core samples are taken across the green and moisture content assessed by feel. This is time consuming, destructive, and subjective. A portable, electronic wave reflectometer uses time domain technology to give fast, accurate, and objective measurements of local soil moisture content. In general, it takes about 2 weeks to identify the desirable soil moisture ranges for the course. A determination can then be made on what greens require hand-watering or whether a complete irrigation cycle is needed. If the green is grid sampled, distribution uniformities similar to those computed with catch cans can easily be computed. Soil-moisture based uniformity coefficients suggest that reductions in irrigation amounts could be merited.

Introduction

The agronomic needs of grass and the demands of the contemporary golfer pose many challenges to managing irrigation on golf greens. The majority of golf courses are currently designed with sand-based greens. Low mowing heights and the desire for firm, fast surfaces mean that the turf must be managed very carefully and intensively. The turf must be kept as dry and firm as possible without allowing it to die. Sand has a low water-holding capacity so the greens are always at risk of drought stress, especially during the hot and dry weather of mid-summer. The inability of the sand to hold water also makes it difficult to maintain proper fertility because nutrients are easily leached. Greens have a high degree of spatial variability, including localized dry spots that can rapidly become critically low in available water. Conversely, if the turf receives too much water, either from rain or excessive irrigation, there is the risk of anaerobic soil conditions and the warm, moist environment is conducive to the spread of fungal diseases. Further, too much water leads to a poor putting surface with foot printing and excessive ball marks. The cost of water and energy means that the conservation of water is not just a matter of environmental stewardship, but is also important to a superintendent's bottom line. Additionally, local municipalities are passing legislation that restricts the amount of water available for commercial and residential irrigation.

Regular monitoring and maintenance of irrigation hardware is needed to reduce water wasted from damaged or mis-aligned sprinkler components. Common remediation

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techniques for improving the infiltration of water into the turf's root zone include aeration, de-thatching, top-dressing with sand and the application of surfactants. Localized dry spots are often hand-watered on an as-needed basis. Fungicides and algaecides are used to combat the effects of disease pressure.

The two most common methods of assessing the amount of moisture in the soil and/or making irrigation decisions are by visual observation of the turf or pulling a soil sample with a probe and determining moisture content by feel. Visual ratings are subjective and can be influenced by light levels and the consistency of the person doing the rating. Errors are also introduced when different people do assessments on different days. However, by the time symptoms of moisture stress are visible to the naked eye, irreversible damage may already have occurred. Moisture-by-feel assessments are also subjective and result in slight damage to the green where the core is taken.

Sprinkler Uniformity

One way for evaluating the performance of an irrigation system is with an irrigation audit. The Irrigation Association has published guidelines for performing irrigation audits (IA, 2007). Catch cans are placed in a grid pattern prior to running the irrigation system for that zone. The amount of water collected in each can is measured and recorded. Two recognized irrigation uniformity coefficients are Christiansen's coefficient of uniformity (CU) and the lower quartile distribution uniformity, DU_{lq}.

Christiansen (1941) developed a coefficient of uniformity that accounts for irrigation amounts above and below the overall average. It is calculated as:

$$CU = 1 - \frac{\sum_{i=1}^{n} |V_i - \overline{V}_{total}|}{\sum_{i=1}^{n} |V_i|}$$

Where:

V_i = The volume captured in a given catch can.

$\overline{V}_{total}$ = Average of all catch can volumes or soil moisture of all readings.

This coefficient treats over-watering and under-watering the same. This coefficient was developed for agriculture and has not gained acceptance in turf where visual quality must be maintained across the entire site (IA, 2003).

DU_{lq}, is calculated as the ratio of the average from the 25% of cans that collected smallest amount of water to the average across all cans.

$$DU_{lq} = \frac{\overline{V}_{lq}}{\overline{V}_{total}}$$

Where:

$\overline{V}_{lq}$ = Average of the lowest 25% of catch can volumes (or soil moisture readings).

$\overline{V}_{total}$ = Average of all catch can volumes (or soil moisture of all readings).

The Center for Irrigation Technology (C.I.T.) has developed a visual tool to depict how sprinklers will distribute water across an irrigated area. The densogram produces a chart that uses a dot matrix to display water distribution on color scale from dark to light with dark being the heaviest concentration and light being no water at all (Zoldoske et al., 1994). This gives visual indications of the size and location of wet and dry areas. This can be done with theoretical sprinkler distribution patterns or catch can data.

Solomon and Kissinger (2005) created a water conservation diagram for turf and landscape irrigation. It is a graphical depiction of how water is applied to an irrigated area. It combines the effect of distribution uniformity and irrigation scheduling decisions into an educational tool that explains the benefits of irrigation improvements.

Irrigation Scheduling

There are 3 common methods for adjusting the run-time based on irrigation audit data.

1. The least conservative adjustment is to correct the run-time so the driest area gets the minimum amount of required water. The scheduling coefficient (SC) is computed as the ratio of the overall catch can average to the average in the driest contiguous percent. The most commonly used portion of total area is one to five percent (Zoldoske, 2003; Connelan, 2004) or even as high as 10 percent (IA, 2003; Zoldoske et al., 1994). The scheduling coefficient is usually calculated with computer software such as the Sprinkler Profile and Coverage Evaluation (S.P.A.C.E.) program from the C.I.T. A rough version can also be calculated by dividing the overall average by the volume of the single driest catch can (Kopec, 1994).

$$SC = \frac{\overline{V}_{total}}{V_{driest}}$$

2. The DU_{lq} can be used to compute a run-time multiplier (RTM) which can then be used to compute an irrigation water requirement:

$$RTM_{lq} = \frac{1}{DU_{lq}}$$

3. An adjustment based on the lower-half distribution uniformity (DU_{lh}) has been found to be a better basis for irrigation scheduling (Dukes et al., 2006). DU_{lh} is similar to DU_{lq} except the numerator is the average of the 50% of cans that collected the smallest amount of water. The run-time multiplier (RTM) is calculated as.

$$RTM_{lh} = \frac{1}{DU_{lh}}$$

In all cases, it is assumed there is a minimum plant water requirement that must be applied to the driest area of the green. In the simplest application, the irrigation water requirement (IWR) is then calculated by multiplying plant water requirement by the run-time adjustment factor. In more sophisticated applications, factors such as weather, soil type, and the maximum desired soil moisture depletion amount are also considered. In any case, this results in some areas receiving more water than necessary. So, there is an advantage to selecting the lowest factor that still maintains acceptable turf quality.

The catch can audit works well for finding flaws in the water delivery system (Mecham, 2001). This includes leaks, damaged heads and misaligned sprinklers. Some drawbacks of the traditional irrigation audit are 1) It is time consuming to set up the cans, run the irrigation system and measure the collected volumes, 2) It is not easy to repeat if modifications are made to the system, 3) It is usually performed for a fee by an outside agent, and 4) It only yields information on how well the water has reached the surface but gives no information on how the water is distributed in the soil. This last point is especially important when irrigation recommendations use the distribution uniformity to set the run time so a minimum amount of water is delivered to the entire irrigation zone. This is because redistribution of water through the turf canopy and within the root zone smoothes out some of the non-uniformity in applied water. Deeper in the soil profile, soil moisture variability is less sensitive to the impact of sprinkler uniformity (Dukes et al., 2006).

Portable Wave Reflectometer

A portable wave reflectometer (PWR) uses time domain technology to give fast, accurate, and objective measurements of local soil moisture content. This gives superintendents the ability to quickly take readings on their greens. Typically, it takes about 2 weeks to ascertain what the threshold water content ranges are for each green. A determination can then be made on what greens require hand-watering or whether a complete irrigation cycle is needed. Soil moisture data collected with such a meter can also be used in place of catch-can volumes to calculate distribution uniformities based on soil moisture content rather than water applied to the surface.

This paper outlines the typical process for integrating a portable wave reflectometer into a turf irrigation program. A comparison of a traditional catch-can and soil moisture based audit is also presented.

Materials and Methods

On the morning of September 6, 2007, an irrigation audit was performed on the putting green for hole 18 at Forest Akers Golf Course in E. Lansing, MI. Wind speed was not measured but was noted to be very low. Hole 18 is a pushup green with approximately 80% Annual Bluegrass. The remaining 20% is Penncross Bentgrass. The shape of the green is a slightly oblong circle with an east-west dimension of 24.7 m and north-south dimension of 25.3 m. This green has relatively poor drainage. The green is irrigated by 4 sprinklers on 18.3 m centers located in the NW, SW, NE, and SE corners of the green (fig. 1). The sprinklers had a throw distance of 18.3 m and rotated in a full circle to water both the greens and the surrounds. A total of 37 plastic cereal bowls were laid out in a grid pattern with a spacing of 0.4 m (fig. 1). The bowls had a diameter of 15.5 cm and a height of 6.7 cm. Before operating the sprinklers, volumetric water content measurements were made with a Field Scout TDR 300 portable wave reflectometer (Spectrum Technologies, Plainfield, IL). Readings were taken to a depth of 12 cm for an estimated sampling volume of 300 cm^3. The probe was inserted directly adjacent to each bowl. The soil moisture readings were geo-referenced with a Garmin 72 (Garmin International, Olathe, KS) hand-held GPS receiver connected to the TDR 300. The sprinkler was then set to run for 20 minutes (fig. 2). The volume of water captured by each bowl was measured and recorded. Approximately 20 minutes after the sprinklers were shut off, the green was again sampled with the reflectometer.

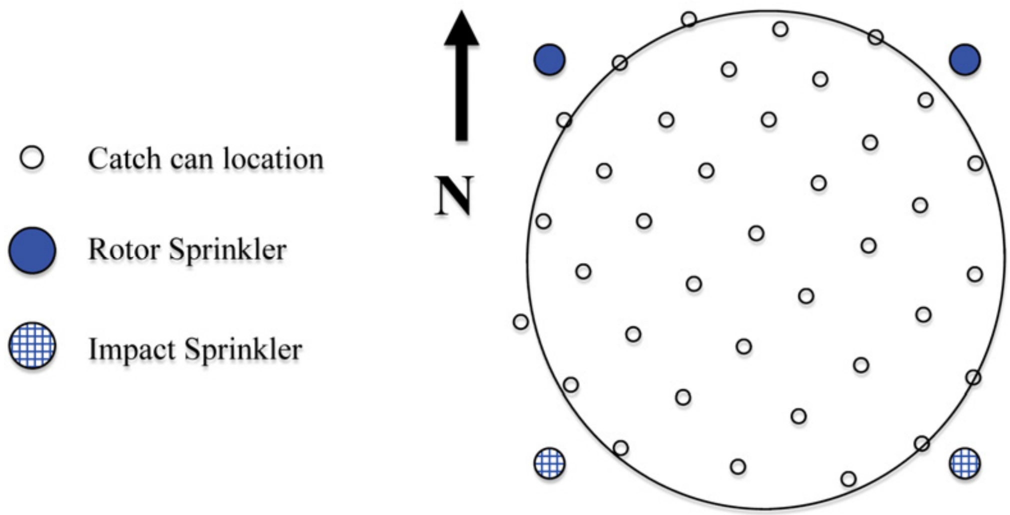

Figure 1. Layout of sprinklers and catch cans on Hole 18.

Figure 2. Sprinklers in operation during audit

Lower quartile and lower half distribution uniformities (DU_{lq}) were calculated for each of three data sets. 2 dimensional color plots of soil moisture and catch can data were created using the SpecMaps mapping utility (Spectrum Technologies, Plainfield, IL).

Discussion

Getting Familiar with the Reflectometer

Although a portable wave reflectometer (PWR) can be a powerful instrument for evaluating soil moisture variability on a golf course green, it must be emphasized that it is only a tool. A PWR is not intended to make a *water/don't water* determination. The superintendent must use the measurements from the PWR, along with information about environmental conditions, the weather forecast, and visual assessments to make decisions about whether and how much water to apply. Accompanying the general guidelines is a review of how a PWR was incorporated into the water management program of Forest Akers Golf Club in E. Lansing, MI.

Initial evaluation

The first, and most important step, is to determine the soil moisture threshold values for each management area. The superintendent should pick out a handful of representative greens and sample them extensively with the PWR. Readings should be taken at known wet and dry areas. When these readings are taken, some other subjective assessment should be done simultaneously. This could by visual assessment of the turf and/or by pulling soil cores. This initial step gives the superintendent a sense of what range of soil moisture values can be expected on the course as well as "ground truths" these numerical soil moisture values with the current evaluation method. Stowell (2006) suggests a moisture content of 15-25% as a threshold value for optimum greens firmness. For any given green, this number will be close to the optimal value. It is best not to do the initial sampling if the ground is very wet from rain or a recent irrigation. If possible, the initial evaluation should be done in the spring because the turf is under less stress.

At Forest Akers, all greens were sampled both at known localized dry spots and at areas that have historically been the last to suffer wilt. Numerical readings from the PWR were compared to visual ratings. Sampling was repeated every day over a two week period. This 2-week period included a light rain and several days of dry weather. After examining the data, it was determined that a value of 18% would be appropriate for the spring. It was concluded that there were 7 greens that could be used to predict the worst-case wilt conditions for the rest of the greens on the course. In other words, if these greens were found to have sufficient soil moisture reserves, the remaining greens would be in a similar state. Only when the representative greens gave low readings would other greens need to be inspected for possible irrigation.

Modifying the criterion

Although the initial evaluation is essential so the PWR can be used to guide irrigation decisions, the interpretation of the readings will necessarily evolve as the season progresses into summer. In the summer, the stress of hot, dry days applies increasing evapotranspirative demand on the grass. Elevated soil temperatures shrink the average root depth down to 2.5cm. USGA greens are especially vulnerable to wilt in these extreme conditions. Therefore, the minimum water content necessary to sustain a playable surface increases until the peak demand period of July and August. During this time, the soil moisture level necessary to maintain healthy turf should be re-evaluated. At Forest Akers, the minimum acceptable soil moisture threshold was raised from 18 to 21% during the summer to account for the increased stress. Summer also brings greater variability in the soil moisture across the greens. Another factor to consider is that the summer is also a time when golf courses will schedule tournaments that can last up to 3 or 4 days. Opportunities to irrigate are more limited and must be timed more precisely than during other times in the season. Under these conditions, the combined information garnered from weather data, visual assessments as well as the PWR provide the superintendent with the information necessary to make informed irrigation decisions.

At Forest Akers, during the summer, water needed to be applied to most of the course just as often as in past years. However, the PWR allowed for the fine-tuning of the amount of water added. Although it was obvious that the localized dry spots would need daily hand watering, the PWR revealed that irrigation could be delayed on some of the areas less prone to stress. Another novel use of the PWR was the use of the 12 cm rods on the pushup greens. In general, the rooting depth of turf on a putting green extends not much more than 7.5 cm. And in the summer this number can be reduced significantly. But, a unique characteristic of older pushup greens is that, because of repeated topdressing, a significant layer of sand builds up above the mineral soil. Therefore, although the root zone may be very dry in the sandy soil near the surface, sufficient moisture can still be stored in the in the mineral soil below. This moisture will be detected if the 12 cm rods are used. The superintendent discovered that the PWR readings, combined with visual inspection of the green, helped determine whether a full irrigation cycle was required, or only a shorter run-time sufficient to replenish the near-surface portion.

At Forest Akers, it was estimated that about two-thirds of the time, the PWR came to the same conclusion as a visual inspection. But, for the other times, the PWR provided information about the soil moisture status that could not easily obtained in other ways.

Audit Results

The raw data from the audit is shown in table 2. 2-dimensional contour plots of soil moisture and catch-can data sets from green 18 are shown in figure 3.

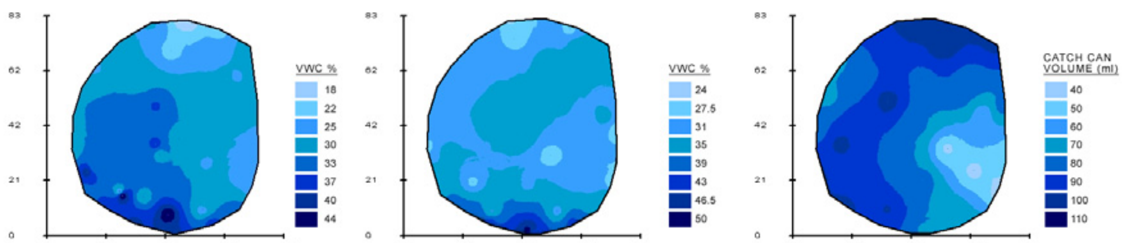

Figure 3. Contour plots of pre-irrigation soil moisture, post-irrigation soil moisture, and catch-can data.

In both soil moisture charts, a wet area is evident in the southwest portion of the green. The driest areas are seen near the northern and southeast edges. The overall average soil moisture increased from 29.0% before irrigation to 32.5% after irrigation. One effect of the irrigation is that the variability of soil moisture is slightly decreased. This is seen both in the plots and in a slight increase in distribution uniformity (table 1). The plot of the catch can data shows that the least amount of water is applied to the southeast and northwest corners while the greatest amount of water is going to the northeast section. It appears that the irrigation pattern is heaviest in a diagonal band that stretches from the northeast to the southwest corners. The volume of water applied then decreases gradually in curved bands that are centered at the sprinkler heads in the southeast and northwest corners. One feature of these figures that stands out immediately is the discrepancy in the northeast corner. This area receives more irrigation water than any other but it is also one of the driest areas - even 20 minutes after the irrigation. This part of the green has historically been susceptible to wilt and this was confirmed by visual inspection before the audit (fig. 4).

Figure 4. Portion of green 18 that received the largest amount of water during the catch-can audit. This area however does not have the highest soil moisture values and is susceptible to wilt.

Lower quartile and lower half distribution uniformity (DU_{lq} and DU_{lh}) and run-time multipliers are shown in table 1. Consistent with earlier findings (Dukes et al. 2006, Mecham, 2001), soil moisture based uniformity is significantly higher than that calculated from the catch can data. Distribution uniformity before and after the irrigation event is very similar. The run-time multiplier based on a lower quartile computation is 33% lower for a soil-moisture based uniformity coefficient. Even for the more conservative calculation based on a lower half computation, the multiplier is on the order of 9% lower. The comparison of uniformity coefficients before and after irrigation agrees with Li et al. (2005) who found that a soil moisture-based coefficient of uniformity before irrigation was found to approximate uniformity after irrigation.

Table 1: Coefficients of uniformity and run-time adjustment factors for 3 audit types.

Audit Type	DU_{lq}	DU_{lh}	RTM_{lq}	RTM_{lh}
CC	64.0	80.2	1.6	1.2
TDR1	81.5	86.7	1.2	1.1
TDR2	83.1	88.5	1.2	1.1

DU, distribution uniformity; RTM, run-time mulitplier LQ, lower quartile; LH, lower half; CC, results from catch-can audit; TDR1, results from first soil moisture audit; TDR2, results from second soil moisture audit.

Conclusions

The ability to capture site-specific soil moisture information is a valuable asset for managing irrigation on golf course greens. While it is not a black box that can definitively say whether or not to apply water, a portable wave reflectometer gives the superintendent immediate assessments of the range and geographic scope of water deficiencies within the green. A superintendent should expect to spend approximately 2 weeks ground truthing the readings from the reflectometer to the conditions on the course. It is advisable to periodically adjust the soil moisture threshold values to account for the increasing demands of the summer. The portable nature of such a meter also allows for the geo-referencing of the data. This data can then be used to create 2-dimensional plots which highlight the spatial variability of soil moisture across the green. Finally, because several data points can be taken essentially simultaneously, soil moisture data can be used to calculate uniformity coefficients that have traditionally been computed using catch-can data. Soil moisture based uniformity, in general, will be higher than that calculated based on water applied to the surface. This leads to shorter predicted irrigated run times without sacrificing turf quality.

Table 2: Volumetric water content and catch can volume data from green 18.

Location	Catch Can volume (ml)	TDR1 (%VWC)	TDR2 (%VWC)	Location	Catch Can volume (ml)	TDR1 (%VWC)	TDR2 (%VWC)
1	92	31.9	41.3	**20**	94	29.7	34.8
2	92	39.1	44.9	**21**	74	31.5	30.1
3	80	44.2	50.3	**22**	61	26.8	30.8
4	68	43.8	48.1	**23**	85	29	31.5
5	89	25.4	31.1	**24**	83	27.9	31.1
3	81	22.1	26.4	**25**	74	33.3	32.6
7	91	29.7	32.6	**26**	75	26.4	31.9
8	74	25.7	28.6	**27**	54	24.6	29
9	54	29.3	30.1	**28**	44	23.9	27.5
10	66	31.5	30.4	**29**	44	25.4	25.4
11	88	32.2	31.1	**30**	72	25.7	29.7
12	72	27.5	31.1	**31**	73	26.4	33.7
13	73	29.3	30.8	**32**	75	26.4	31.5
14	65	22.8	30.4	**33**	94	27.5	34
15	77	38	40.2	**34**	98	19.9	25.7
16	30	27.2	33.3	**35**	101	23.9	26.4
17	37	27.5	27.9	**36**	97	24.6	32.6
18	38	29	25.7	**37**	108	27.9	33.3
19	71	34.8	34.8				

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