Variability in Turfgrass Water Requirements on a Golf Course

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Abstract. Microclimates can vary significantly across a golf course, and directly influence turf irrigation requirements. The objective of this study was to quantify the extent of this variability in water demand, and evaluate the accuracy of weather station-generated evapotranspiration (ET) estimates for determining irrigation need for one Kansas golf course. Evaporation was measured using black Bellani plate atmometers placed on four golf tees and near the weather station at the Manhattan Country Club, Manhattan, Kans., in 1995 and 1996. Evaporation was measured on a total of 62 precipitation-free summer days in 1995 and 1996. Probably because the weather station was situated over nonirrigated turf, evaporation at the weather station was up to 22% higher than that at locations on tees. Evaporation varied by >20% among tees. Evaporation on a north-facing slope was 8% lower than that on a level surface or south-facing slope. Weather station-estimated empirical ET (Penman model) was consistently higher than ET estimated from atmometer evaporation, particularly when ET was >4 mm·day⁻¹. Superintendents should be aware of the potential variability in water demand across a golf course, and that weather-station ET estimates may differ from turf ET primarily because of microclimatic differences and potential inaccuracies in the empirical model employed by the weather station to estimate turf ET.

Turf water requirements are generally assumed to vary extensively over a golf course, depending upon microclimate. The extent of this variability, however, has not been measured. Golf course superintendents often have a single irrigation schedule for the entire course, although significant variability in evapotranspiration (ET) may occur. In many cases, irrigation requirements are determined empirically from weather data collected at a single location, without regard to variability in water demand across the site. In addition, weather stations are usually located in obscure parts of the courses that may not reflect “average” conditions on the rest of the course.

Variability in turf ET results because microclimates differ in solar radiation, temperature, wind speed, and relative humidity. Kentucky bluegrass ET increased linearly with increasing solar radiation (Feldhake et al., 1983). Warm- and cool-season grasses exhibited higher ET rates as soil temperature in-

creased from 13 to 29 °C (Feldhake and Boyer, 1986). Turfgrass ET generally increases with increasing wind speed and decreasing relative humidity (Feldhake and Boyer, 1988).

Feldhake and Boyer (1990) investigated the variability in evaporation across a 3-ha amphitheater-shaped pasture that drained to the northwest with slopes ranging from 8% to 60%. Within this area, average daily wind speed varied by 164% and average daily solar radiation by 34%. Resultant evaporation varied by up to 36%. No information about variability in ET across sites on a golf course has been published.

The objectives of this study were therefore to measure variability in evaporation at six locations on a golf course, and to compare atmometer-estimated ET to ET estimated empirically from weather data collected at an on-site weather station.

Materials and Methods

The study was conducted at the Manhattan Country Club, Manhattan, Kans. (lat. 39°3'N, long. 96°46'W, 337 m elevation), during Summers 1995 and 1996. Evaporative demand was measured using black Bellani plate atmometers described by Qian et al. (1996). The plate consists of a plane circle of porous porcelain, 6.5-cm diameter, covering the large end of a funnel-like base. Water is conducted to the funnel through a tube from a flask that serves as a reservoir (Carder, 1960; Livingston, 1935). In 1995, five white, 26 × 24 × 15-cm boxes, each holding two black Bellani plates and respective water reservoirs, were placed on four golf tees (nos. 3, 5, 7, and 18) and near the weather station (WS). In 1996, a box was also placed at tee no. 4, but removed from tee no. 5.

Each box had two holes cut in its top to match the diameter of the plate's surface. A hinged door on the side of the box allowed easy removal of water reservoirs. Boxes were mounted on poles so that the flat surface of plates was supported ≈1 m above the ground.

Tee no. 3 was located in an elevated, exposed area. Tee no. 4 was bounded by trees (≈4 m high) from northeast to southwest. Tee no. 5 was located in an open area at the base of a hill (≈15% slope) which extends upward to the southwest. Tee no. 7 was closely bordered by trees and shrubs (≈3 m high) to the east and west. Tee no. 18 was exposed to the southwest with a line of trees (≈5 m high) to the north. The weather station was located in an open area and turf was not irrigated at this site.

In 1996, atmometers were placed on tees no. 3, 4, 7, and 18. In addition, atmometers supported at 0.3 m above the ground were installed on north- (≈28% slope) and south-facing (≈34% slope) slopes, and the level surface of tee no. 18. Boxes were mounted on the middle of slopes so that the plate surface was level. Evaporation from each atmometer was measured on 34 precipitation-free days between 13 June and 30 Aug. 1995 and 28 precipitation-free days between 10 June and 15 Aug. 1996, by weighing a 250-mL Erlenmeyer flask containing distilled water that served as a reservoir. Mass of water lost was converted to depth.

Evaporation data from tees no. 3, 7, 18, and the weather station were measured in both years, and were used for analysis of year effects and year × location interactions on evaporation. To test for differences in evaporation between years, and for the year × location interaction, hypotheses were tested using a mixed model analysis of variance (ANOVA). Since locations were chosen to represent distinctly different local environmental conditions, their effects were considered fixed. Remaining factors, years, atmometers, and days, as well as interactions, were assumed to be random.

The 2 years of atmometer evaporation data were also analyzed separately regardless of the significance of the year × location interaction because of inconsistent arrangement of atmometer locations. For each year, data were subjected to repeated measures ANOVA. Plate within location was used to test for differences among locations and conservative degrees of freedom for day effects and day × location interactions (Cochran and Cox, 1957). For the conservative degrees of freedom, day, day × location, and their error degrees of freedom were divided by the degrees of freedom for day, thus increasing the critical F-value needed to detect significance. Mean separation was done by Tukey's honestly significant difference (HSD) ($P < 0.05$) (SAS Institute, 1989).

The black Bellani plate atmometer provides a relatively accurate estimate of turf ET under well-watered conditions (Qian et al., 1996). Evaporation for each location on each measurement day was converted to an ET estimate for perennial ryegrass (*Lolium perenne* L.) turf mowed at 1.25 cm using an empirical model developed previously by re-

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gressing plate evaporation on lysimeter ET under well-watered conditions (Fry et al., 1993). Evapotranspiration estimates provided by the Penman model (Jensen et al., 1990) using weather station (Rainbird Golf, Azusa, Calif.) data were compared with ET estimates calculated from atmometer evaporation at each site, using regression analysis.

Results

Mean daily evaporation over three golf tees was generally higher in 1995 than in 1996 (8.2 vs. 7.6 mm·d⁻¹), probably because higher temperatures (means of 25.3 and 24.7 °C) and solar radiation (means of 19.1 MJ·m⁻²·d⁻¹ and 18.5 MJ·m⁻²·d⁻¹) were measured in 1995 than in 1996, respectively.

In both years, location had a significant impact on atmometer evaporation (Table 1). In 1995, evaporation at the weather station (WS) was highest, and that at tee no. 7 was lowest among all locations (Table 2). Evaporation at tees no. 3, 5, and 18, was ≈10% lower than that at the weather station.

In 1996, evaporation at tee no. 7 was 21% lower than that at the weather station, and that at tees no. 4 and 18 was ≈10% lower than that at the weather station (Table 2). Evaporation at tee no. 3 was similar to that at the weather station.

Evaporation on a north-facing slope was 8% lower than that on a south-facing slope or that on a level surface in 1996 (Table 3). Irrigation applications may, therefore, need to be adjusted on the basis of topography to account for varying water requirements.

Significant ($P < 0.001$) linear correlations ($r^2 = 0.61$ to 0.85) were observed between weather station-generated ET estimates and atmometer-estimated ET at each location (Fig.

1). Weather station-generated ET was consistently higher than atmometer-estimated ET, particularly when ET was higher than ≈4 mm·d⁻¹.

Discussion

Two potential factors probably contributed to the results reported herein. The consistent difference between atmometer evaporation and that predicted by the weather station were probably due to lack of irrigation at the weather station site and inaccuracies in the Penman model.

Variability in atmometer evaporation among tees indicates the importance of accounting for microclimate differences on the golf course and adjusting irrigation on a site-by-site basis. At the Manhattan Country Club, the weather station is situated in an open area and surrounding turf is not irrigated. Air temperatures over nonirrigated areas can be 2 to 5 °C warmer than adjacent irrigated areas, with corresponding lower relative humidities and greater vapor pressure deficits (Jensen et al., 1990). This probably contributed to the higher evaporation measured at the weather station each year. Superintendents should attempt to locate a weather station in an area most representative of the entire golf course. Furthermore, the station should be situated upon irrigated turf to improve accuracy of ET estimates. This may require installation of an irrigation system that delivers water precisely enough to avoid application on environmental sensors, including the rain gauge.

The weather station employs the Penman model, which estimates ET for grassy vegetation at ≈15 cm tall. Atmometer-estimated ET was derived from a model developed for perennial ryegrass maintained at golf course

fairway height (2 cm). These factors, plus the fact that the weather station model is essentially estimating evaporation whereas the atmometer measures evaporation, probably contributed to differences observed between atmometer-estimated ET and weather station-estimated ET.

Overestimation of turf water requirements by an empirical weather-based model has been previously reported. The Penman-Monteith model overestimated turf ET on days when water demand was high in Kansas (Qian et al., 1996). Assuming well-watered conditions, using weather station-estimated ET as the sole guide for irrigation would have resulted in excess application of ≈20 mm water per week on tee no. 7, the tee with lowest water demand. Hence, weather station-estimated ET should not be used without rather subjective crop coefficients to determine turf water requirements.

Note that the disparate ET estimates (up to 20%) among sites measured in this study were of the same order of magnitude as the water delivery inefficiency of most irrigation systems. However, we were constrained to placing atmometers in areas of the course experiencing minimal play and, thus, did not measure the ET extremes on the course. We expect that, in fact, larger site-to-site disparities exist on this, and other, golf courses. Furthermore, potential ET variations on a course, coupled with nonuniform irrigation distribution, could result in even greater disparity between water need and application. Thus, identification of site-to-site variations in water demand within a golf course is clearly important.

This study provides information on the variability of turf water requirements across one golf course. The results indicate that it may be beneficial for superintendents to delineate areas of the golf course with differing water requirements (e.g., low-, intermediate-, and high-water use areas) and accordingly schedule irrigation to meet demand. Atmometers, such as those used in this study, would be useful for this purpose. The use of other tools in combination with ET estimates, including the superintendent's horticultural knowledge, soil water measurements, and visual turf appearance, will also obviously result in the most efficient water application.

Table 1. Analysis of variance for atmometer evaporation on golf tees at the Manhattan Country Club, Manhattan, Kans., in 1995 and 1996.

Source	1995		1996	
	df	Mean square	df	Mean square
Location (L)	4	43.81*	7	28.14**
Plate (location)	5	6.47	8	1.83
Days (D)	33 (1 ²)	40.97***	27 (1)	78.33***
L × D	132 (4)	1.68**	189 (7)	1.90***
Error	165	0.41	216	0.32

²Conservative degrees of freedom. For the conservative degrees of freedom, day, day × location, and their error degrees of freedom were divided by the degrees of freedom for day, thus increasing the critical F value for significance.

*, **, ***Significant at $P \leq 0.05$, 0.01 , and 0.001 , respectively.

Table 2. Atmometer evaporation at the Manhattan Country Club, Manhattan, Kans., in 1995 and 1996.

Location	Evaporation (mm·d ⁻¹) ²		% of Weather station	
	1995	1996	1995	1996
Weather station	9.6 a ³	8.3 a	100	100
Tee no. 3	8.5 b	8.4 a	91	101
Tee no. 4	---	7.7 b	---	90
Tee no. 5	8.8 b	---	94	---
Tee no. 7	7.4 c	6.7 c	78	79
Tee no. 18	8.6 b	7.8 b	91	93

²Means for 34 d between 13 June and 30 Aug. 1995, and 28 d between 10 June and 15 Aug. 1996.

³Mean separation within columns by Tukey's HSD, $P \leq 0.05$.

⁴Evaporation at these tees not evaluated.

Table 3. Evaporation on north- and south-facing slopes at tee no. 18 at the Manhattan Country Club, Manhattan, Kans., in 1996.

	Evaporation	
	(mm·d ⁻¹) ²	% of level surface
Level surface	7.1 a ³	100
South-facing slope	7.1 a	100
North-facing slope	6.5 b	92

²Mean for 28 d between 10 June and 15 Aug. 1996.

³Mean separation within columns by Tukey's HSD, $P \leq 0.05$.

Fig. 1. Weather station-estimated ET vs. atmometer-estimated ET on tees no. 3, 4, 5, 7, 18, and the weather station in 1995 (●) and 1996 (○). The line represents a 1:1 relationship.

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