IRRIGATION SCHEDULING ON SAND-BASED CREEPING BENTGRASS

Evaluating ET Estimation, Capacitance Sensors and Deficit Irrigation in the Upper Midwest

By J.F. Sass, M.S. Student, University of Minnesota, St. Paul
and B. P. Horgan, Assistant Professor, University of Minnesota, St. Paul

Abstract

During the 2003 and 2004 growing seasons, research was conducted on a 'Providence' creeping bentgrass (Agrostis stolonifera L.) sand green at the University of Minnesota St. Paul campus to evaluate the use of ECH2O capacitance soil moisture sensors and FAO 56 ET (Food and Agriculture Organization of the United Nations Evapotranspiration) estimation in scheduling turfgrass irrigation by applying prescribed irrigation treatments based on replacement of 100% actual ET loss and either 100% or 80% of FAO 56 estimated ET loss in a series of four 10 day experiments. Turf quality and soil moisture response to deficit irrigation treatments were also assessed. FAO 56 ET estimation accurately predicted actual ET, and a summer crop coefficient (kc) of 0.98 was calculated. ECH2O probes were highly sensitive to changes in soil moisture. There were no significant differences in root zone water storage fluctuation between treatments. Lysimetry and sensor data indicated the presence of a substantial thatch effect on irrigation infiltration and ET loss. Daily irrigation consistently wetted the soil no deeper than 10 cm. There were no statistical differences in turf quality between irrigation treatments in any experiment, suggesting that replacement of 80% of actual ET is sufficient to maintain acceptable daily irrigated creeping bentgrass in Minnesota.

Introduction

Water use in turfgrass culture is under intense scrutiny and has been identified by regulatory agencies and environmental groups as a focal point for reducing consumption of water. In addition to concerns over the scarcity of water supplies, the increasing monetary cost of water, electricity and irrigation system components are factors in the push for conserving water resources.

Carrow (6) identified efficient irrigation scheduling as one particular strategy that can conserve water resources in the management of turfgrass. Efficient irrigation scheduling reduces water waste by replacing only the amount of water lost to turfgrass use, or evapotranspiration (ET). To improve irrigation scheduling efficiency, various technologies are being evaluated by researchers as tools to augment or replace the art of irrigation.

Capacitance soil moisture sensors use the dielectric properties of soil to indirectly measure soil water content. Measurement of the frequency of an oscillating signal sent through a circuit (soil) yields an indirect measurement of soil moisture (13). Capacitance sensors are extremely sensitive to small changes in soil water content and are suitable for irrigation scheduling of citrus crops in the fine sand soils of Florida (8, 12). The suitability of capacitance sensing for scheduling turf irrigation, however, is not known.

Turfgrass water requirements can be accurately predicted by equations which use weather data to estimate ET (2). In contrast to soil moisture sensors, ET estimators are used widely to schedule turfgrass irrigation. Arizona (4) and California (14) currently use ET estimation as the basis for establishing irrigation scheduling guidelines for all agricultural and horticultural crops, including turfgrass. The Food and Agriculture Organization of the United Nations selected an updated version of the Penman-Monteith ET equation as the recommended single ET estimation model for crop irrigation and designated it FAO 56 (2).

In addition to efficient irrigation scheduling, Carrow (6) identified deficit irrigation as another important water conservation strategy. Many species of turf can be irrigated with less than 100% replacement of ET loss and maintain acceptable turf quality, resulting in substantial water savings (10). Creeping bentgrass (Agrostis stolonifera L.) specific deficit irrigation research is limited to DaCosta and Huang (7), who recently reported that replacement of 80% ET loss is adequate to maintain turf quality under fairway conditions in a sandy loam soil during the summer in New Jersey.

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The objectives of this research were: evaluate the accuracy of FAO 56 ET estimation and develop a summer-use FAO 56 crop coefficient for creeping bentgrass turf in Minnesota; evaluate the response of ECH2O (Decagon Devices, Pullman, WA) capacitance sensors to changes in soil moisture by varying irrigation treatments and explore minimum ET replacement percentages and the possibility of using deficit irrigation strategies for creeping bentgrass turf in Minnesota.

Project Design

Six individual 5 m by 5 m plots were equipped with quarter circle spray heads on each corner and individual station at a satellite controller. Daily plot irrigation delivery accuracy relative to the target volume and Christiansen's coefficient of uniformity (16) of 70-90% was maintained and verified throughout each of four 10-day experimental periods by measuring individual plot irrigation input with three volumetric jars per plot.

The 35.6 cm deep root zone had a textural composition of 97.2% sand, 1.4% silt, and 1.4% clay, organic matter content of 1.9% (by weight), pH of 7.7, and C.E.C. of 2.0 meq 100 gm-1. Turfgrass cover was composed of 85-90% 'Providence' creeping bentgrass and 10-15% annual bluegrass (Poa annua L.). The thatch/mat was approximately 1.3 cm thick and did not significantly change for the duration of the project. During the experimental periods, daily mowing at 5 mm was performed in addition to the prescribed irrigation treatments by use of a walk-behind reel mower. Fertility was maintained outside of experimental periods at 14-day intervals at 4.8 to 9.7 kg N ha-1 yr-1; total fertility input for the plots was approximately 220 kg N ha-1 yr-1, 122 kg P2O5 ha-1 yr-1, and 292 kg K2O ha-1 yr-1. All other maintenance activities such as topdressing, verti-cutting and disease management were performed as needed and scheduled so as not to occur during experimental periods. Rainfall was eliminated by use of a polypropylene rain cover which could be installed within 5 minutes. Drainage losses or surface runoff into or out of the lysimeters did not occur as verified by leachate collection devices. Therefore, all water inputs were attributed to the prescribed irrigation treatments, and all losses were attributed to ET.

Table 1.

Experiment	Date	FAO 56 ET (mm day^{-1})	Temp °C	RH (%)	Wind Speed (m sec^{-1})	Solar Radiation (W m^{-2})
1	Aug 2003	5.2	24.2	71.2	1.8	6550
2	Aug 2003	4.0	20.9	65.5	2.0	4997
3	July 2004	4.8	23.5	76.1	1.9	6301
4	Aug 2004	3.4	16.7	77.4	2.6	4671

Three treatments consisting of daily irrigation inputs were replicated in triplicate and arranged as a randomized complete block design. Treatment A consisted of replacing 100% of lysimeter indicated ET loss, treatment B consisted of replacing 100% of FAO 56 estimated ET loss and treatment C consisted of replacing 80% of FAO 56 estimated ET loss. Experiments 1 (100% lysimeter vs. 100% FAO 56) and 2 (100% lysimeter vs. 80% FAO 56) were completed in August and early September of 2003 and replicated in July and August of 2004 as experiments 3 (100% lysimeter vs. 100% FAO 56) and 4 (100% lysimeter vs. 80% FAO 56). Preliminary work at the site indicated that the FAO 56 model closely predicted actual turf ET (data not shown). Therefore, 80% of the FAO 56 estimated ET was taken as equivalent to 80% actual turf ET.

Within each of the six plots, a free draining 19 L bucket-type lysimeter as described by Feldhake et al. (9) was installed and seeded during green construction in 1996. The lysimeters were level with and composed of an identical root zone mix as the surrounding turf. Lysimeter weight for each plot was measured twice daily, once immediately before irrigation and again immediately after irrigation, using an Ohaus (Pine Brook, NJ) I-20W digital scale. Following Aronson (3), change in lysimeter weight was correlated to a depth of water lost or gained. In this manner, both 24 hr ET loss and irrigation input (in mm) was calculated. Minimum detectable irrigation input was 0.2 mm.

Model EC-20 ECH2O capacitance soil moisture sensors were used to measure soil moisture within ±1% volumetric water content (?) with a resolution of 0.2%. Prior to the field experiments, soil specific sensor calibration (r2 = 0.98) was achieved by comparing triplicate measurements of known volumetric water content against the sensor output. One meter adjacent to the weighing lysimeter in each plot, ECH2O probes were inserted horizontally into the soil at 5, 10, 15, 20 and 25 cm depths in a spiral staircase pattern.

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Triplicate plot TDR readings (mean of 0-11.7 cm soil depth) were recorded daily prior to irrigation using a Spectrum Technologies (Plainfield, IL) Field Scout TDR 300 soil moisture probe. Plot turf quality was rated at noon on days 1, 4, 7 and 10 of each experiment using a scale of 1 to 9 (1=dead, 6=acceptable and 9=ideal). Rating score was based on visible turf color, density and leaf texture.

Weather and class A pan evaporation data was collected from an automated on-site weather station. Average temperature, relative humidity, wind speed and solar radiation data was downloaded and software was used to generate FAO 56 ET estimates using the hourly step method (eq. 1) as described by Allen et al. (2):

(eq. 1)

Where ETo is the reference evapotranspiration (mm hour-1), Rn is the net radiation at the grass surface (MJ m-2 hour-1), G is the soil heat flux density (MJ m-2 hour-1), Thr is the mean hourly air temperature (°C), is the saturation slope vapor pressure curve at Thr (kPa °C-1), is the psychrometric constant (kPa °C-1), e° (Thr) is the saturation vapor pressure at air temperature Thr (kPa), ea is the average hourly actual vapor pressure (kPa), and u2 is the average hourly wind speed (m s-1).

Table 3.

Experiment	Treatment	Mean Daily ET loss (mm)			Mean Daily Irrigation (mm)	
		Lysimeter†	FAO 56	ECH_2O sensor‡	Lysimeter†	ECH_2O sensor‡
1	100% Lysimeter	5.2	5.2	1.7	5.4	1.5
	100% FAO 56	5.1		2.1	5.0	2.0
2	100% Lysimeter	4.4	4.0	1.6	4.4	1.7
	80% FAO 56	3.8		0.8	3.3	0.7
3	100% Lysimeter	4.9	4.8	1.1	4.9	1.4
	100% FAO 56	5.0		1.4	5.0	1.4
4	100% Lysimeter	3.1	3.4	0.7	3.2	0.7
	80% FAO 56	3.0		0.7	2.8	0.5

† 0 to 28 cm depth
‡ 5 to 25 cm depth

Daily reference ET (ETo) was calculated by summing the predicted ET from each of the 24 hourly time steps. Preliminary analysis of the FAO 56 model on this site in June and July of 2003 showed good response to environmental conditions when regressed against actual turf ET, with crop coefficient (kc) values ranging from 0.85 to 1.05. Published FAO 56 specific crop coefficient data was limited to a suggested kc of 0.90-0.95 for all cool season grasses by Allen et al. (2). On the basis of the preliminary work on-site and the recommendation by Allen et al., a working crop coefficient of 1.0 was selected and used throughout the study period to yield the predicted turf ET (ETcrop) by the formula ETcrop = ETo * kc. Daily means of FAO 56 ET estimates, along with daily means of required weather data, are displayed in Table 1. The substantial differences in weather conditions and resulting ET demand among the four experiments meant that comparisons of treatment effects could be made within but not between experiments.

FAO 56 ET estimation

Over the four experimental periods, FAO 56 ET estimation accurately predicted actual ET (r2= 0.84) (Fig. 1). The relationship between class A pan evaporation and actual ET was not as strong (r2 = 0.40). The daily mean computation procedure outlined by Brown et al. (5) yielded an FAO 56 mean crop coefficient of 0.98 (standard error of 0.02) and a class A pan evaporation coefficient of 0.81 (standard error of 0.04).

Lysimeter indicated irrigation inputs were not significantly different in experiments 1, 3 (100% lysimeter ET vs 100% FAO 56 ET), or 4 (100% lysimeter ET vs 80% FAO 56 ET). In experiment 2, 80% FAO 56 ET irrigation inputs were significantly lower than 100% lysimeter ET irrigation (Table 2).

The 10-day treatment mean of irrigation delivery accuracy was within ±4% of the target volume for each treatment in each experiment (Table 2). The deficit irrigation treatments in experiments 2 and 4 were 83 and 82%, respectively, of FAO 56 estimated ET.

The differences in daily mean lysimeter measured ET between treatments were within 0.1 mm day-1 in experiments 1, 3, and 4. Daily mean lysimeter measured ET for 80% FAO 56 irrigated plots was 0.6 mm day-1 lower than 100% lysimeter irrigated plots in experiment 2 (Table 2). However, none of the differences in lysimeter ET was significantly different.

Turf quality ratings remained above acceptable levels and were not significantly different between treatments at either the start or end of each experiment. There were also no significant changes in turf quality from day 1 to day 10 in any treatment during each experiment (Table 2). This suggests that daily deficit irrigation scheduling which seeks to replace 80% of actual ET is sufficient to maintain turf quality of creeping bentgrass for at least 10-day periods during the summer in Minnesota.

Table 2.

Experiment	Date	Irrigation Replacement Treatment		Mean Lysimeter Measured ET ($mm\ d^{-1}$)	Mean Lysimeter Measured Irrigation ($mm\ d^{-1}$)	Turf Quality (d1) (1-9)	Turf Quality (d10) (1-9)	
1	8/8 - 8/17/2003	100% actual ET		5.2†	5.4	7.0	6.9	*NS*‡
		100% FAO 56 ET		5.1	5.0	6.8	6.8	*NS*
			LSD	*NS*	*NS*	*NS*	*NS*	
2	8/25 - 9/3/2003	100% actual ET		4.4	4.4	6.9	7.0	*NS*
		80% FAO 56 ET		3.8	3.3	6.8	6.1	*NS*
			LSD	*NS*	*0.90*§	*NS*	*NS*	
3	7/13 - 7/22/2004	100% actual ET		4.9	4.9	6.6	6.2	*NS*
		100% FAO 56 ET		5.0	5.0	6.6	6.3	*NS*
			LSD	*NS*	*NS*	*NS*	*NS*	
4	8/9 - 8/18/2004	100% actual ET		3.1	3.2	6.4	6.2	*NS*
		80% FAO 56 ET		3.0	2.8	6.7	6.3	*NS*
			LSD	*NS*	*NS*	*NS*	*NS*	

† Data presented are grand means of daily means by treatment within each 10 d experiment.
‡ *NS*, nonsignificant at the 0.05 level.
§ Fisher's LSD values are reported where significant differences at the 0.05 level occur.

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ECH2O Capacitance Sensor Performance

The ECH2O sensors showed a definite response to the irrigation treatments (Fig. 2). Soil moisture fluctuation decreased with increasing soil depth throughout the four experiments, with few exceptions (Fig. 3). Sensor response to irrigation input at the 5 cm depth was significant following each irrigation application in each treatment. Sensor response to irrigation input at the 10 and 15 cm depths varied slightly with treatment, and more importantly, with irrigation volume. In experiment 2, sensor data indicated a difference in wetting front and water storage between treatments over the 10-day period. The 100% lysimeter ET replacement treatment seemed to maintain positive water storage at the 5 and 10 cm depths, with a slightly negative trend at the 15 cm depth. The 80% FAO 56 ET treatment appeared to maintain soil moisture at the 5 cm depth, while losing soil moisture at the 10 and 15 cm depths (Fig. 4). In experiment 4, cool and cloudy conditions dramatically lowered ET and irrigation treatment volumes, resulting in significant sensor response to irrigation input only at the 5 cm depth, regardless of treatment. Throughout the experiments, sensor response to irrigation input at the 20 and 25 cm depths was largely restricted to deviations from the normal daily irrigation pattern, regardless of treatment. Although the 80% FAO 56 ET deficit irrigation treatments showed a more muted response to irrigation inputs, volumetric water content changes throughout the entire root zone as indicated by the ECH2O sensors were not significantly different between treatments in any experiment.

Table 4.

Experiment	Irrigation Replacement Treatment		Mean TDR Volumetric Water Content (0-11.7 cm) (%)	Mean ECH_2O Volumetric Water Content (0-10 cm) (%)	*LSD*
1	100% actual ET		16.5†	12.8‡	*0.74*§
	100% FAO 56 ET		15.7	13.6	*0.46*
		LSD	*NS*¶	*0.16*	
2	100% actual ET		17.7	13.7	*1.05*
	80% FAO 56 ET		14.3	12.7	*1.04*
		LSD	*1.42*	*0.39*	
3	100% actual ET		16.8	13.9	*0.90*
	100% FAO 56 ET		17.5	14.0	*0.58*
		LSD	*NS*	*NS*	
4	100% actual ET		16.5	13.8	*1.06*
	80% FAO 56 ET		16.5	13.7	*1.22*
		LSD	*NS*	*NS*	

† Data presented is the grand mean of daily mean treatment TDR volumetric water content.

‡ Data presented is the grand mean of daily mean treatment ECH_2O volumetric water content aggregating the 5 and 10 cm depth sensors.

§ Fisher's LSD values are reported where significant differences at the 0.05 level occur.

¶ *NS*, nonsignificant at the 0.05 level.

Discussion

In addition to passive collection of soil moisture status in research and cropping systems, capacitance sensors such as the ECH2O probe show great promise in playing an active role in irrigation management. Sensor-activated rain shut-off switches represent one simple use of incorporating soil moisture sensors into

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conservation-based irrigation management. Fares and Alva (8) demonstrated that capacitance sensors could be used to schedule irrigation of citrus trees in Florida by establishing set points in the context of plant available soil water content using data collected by sensors.

Comparison of the lysimeter and ECH2O sensor indicated irrigation inputs suggests that over 70% of soil moisture fluctuation occurred in the top 4 cm of soil (Table 4). The depth of irrigation, rather than treatment, appeared to be most important in determining the depth of wetting. Project data suggests that the first 3 mm of irrigation applied daily was intercepted by the top 4 cm of soil. Young et al. (15) found a similar occurrence while investigating the use of TDR in large turf lysimeters in Arizona. In their work, TDR probes installed beneath the thatch layer consistently estimated lower water content than that measured by weight. In our research, the surface penetrating TDR probes measured higher soil water content than that measured by the 5 and 10 cm depth ECH2O probes (Table 3).

Results from our research indicate that daily irrigation which seeks to replace 80% of estimated ET is sufficient to maintain creeping bentgrass quality during the summer months under 10-day intervals. This agrees with the findings of DaCosta and Huang (7), who report that creeping bentgrass on a sandy loam soil maintained at 0.95 cm during the summer could be irrigated on a three times per week frequency with as little as 80% of actual ET and maintain acceptable turf quality. Deficit irrigation has great potential in conserving water resources in areas such as Minnesota where rainfall occurs at fairly regular 10- to 14-day intervals since low irrigation volumes could be used to simply maintain minimum soil moisture levels between periodic rain events. These rain events, rather than irrigation, would serve as the primary means to fully recharge the root zone.

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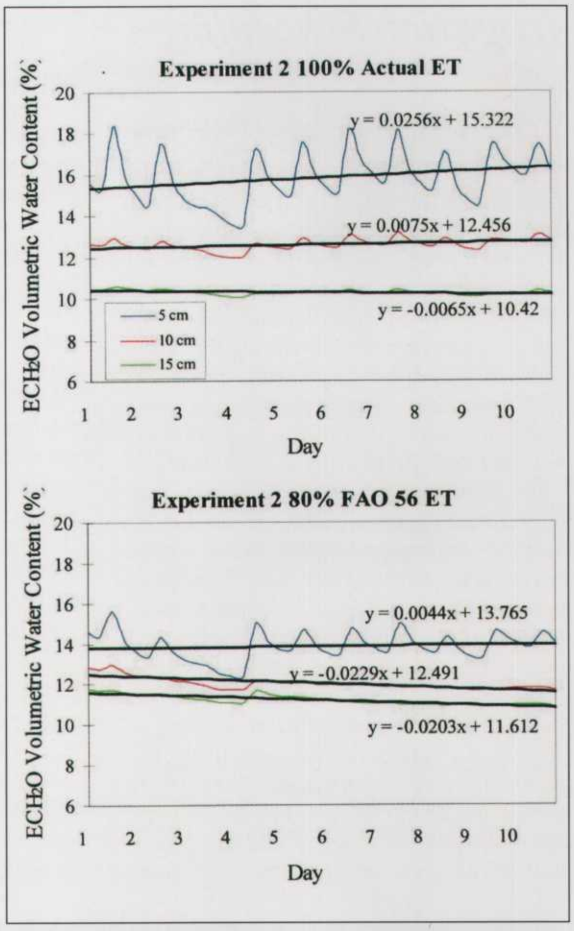
Experiment 2 100% Actual ET

Experiment 2 80% FAO 56 ET

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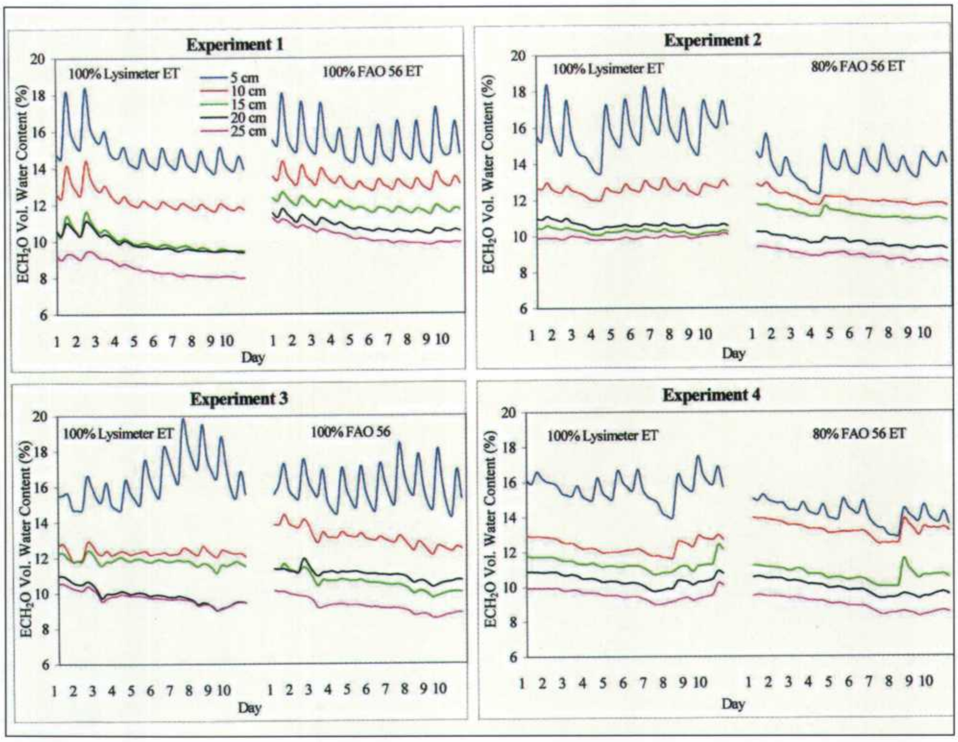
Our data seems to validate the adage that watering daily with low irrigation volumes is less water efficient compared to deep and infrequent irrigation. Under daily shallow irrigation, a large proportion of the irrigation volume applied remains in the upper 5 cm of soil and is subject to high rates of evaporation. Because of this, a lower proportion of water delivered to the turf surface reaches the plant roots and is available for root uptake. Deep and infrequent irrigation should be more water efficient since the lower frequency interval reduces the impact of water entrapment and evaporative losses from the upper soil and thatch layer. However, Huang and Liu (11) found that during summer months, the majority of creeping bentgrass root biomass was situated in the upper 10 cm of soil. In this case, irrigating heavily enough to wet soil past the 10 cm root zone depth will result in water losses to deep infiltration (internal drainage). A highly water efficient irrigation scheduling program seeks to limit losses both to entrapment/evaporation at the soil surface as well as deep infiltration past the root zone.

Confusion over the origin and turf specific applicability of the many different equations has made many turf irrigators wary of ET estimation. FAO 56 represents an excellent opportunity to incorporate standardized and accurate ET estimation into turf irrigation scheduling by golf course superintendents. The American Society of Civil Engineers (A.S.C.E) has recently recommended adoption of an updated equation for ET estimation. Grass reference ET estimated by the A.S.C.E. standardization is identical to FAO 56 using the daily time step procedure (1). Slight differences between the two equations when using hourly time steps may require additional research to translate FAO 56 specific crop coefficients into suitable form for use with the new standardization.

Conclusion

Results from this project indicate that both FAO 56 ET estimation and ECH2O capacitance soil moisture sensors have the capability to serve as the foundation for turf irrigation scheduling which should result in the conservation of water resources while maintaining turf quality.



These technologies can be used either to schedule irrigation applications independent of human input or to augment the art of irrigation scheduling practiced by many turfgrass managers. Deficit irrigation also shows great promise in conserving water resources and should be incorporated into existing and future turf irrigation best management practices. More research is needed to realize the potential of these technologies in meeting water conservation goals in the management of turfgrass.

Acknowledgements

Funding and technical support for this research provided by the Toro Company Center for Advanced Turf Technology. Special thanks to Dave Ruschy of the University of Minnesota-St. Paul Climate Center, Dr. Van Cline and Troy Carson of the Toro Company, and to Dr. Don White, Dr. Eric Watkins, and Andrew Hollman of the University of Minnesota.

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