Forget Milk. Got Water?

Evapotranspiration estimation, *in situ* sensing headline technological advances

By Jon Sass and Brian Horgan

Irrigation of turfgrass is increasingly targeted by regulatory agencies and environmental groups across the United States as a focal point for reducing consumption of water. As a perceived "luxury" crop, the turfgrass industry can expect to bear the brunt of further water restrictions and increased costs associated with irrigation.

Turf irrigation practices based on habit or observation of qualitative criteria such as color can lead to overwatering, wasting valuable water resources in addition to causing or exacerbating a wide range of turf problems (Archambeau, 2003; Carrow et. al., 2002a and 2002b).

Clearly, the health of your turf and even your bottom line as a money manager depend on delivering only the amount of water your turf needs: no more and no less. How much should we water on a given day? Let's backtrack for a moment and revisit a basic hydrologic equation depicting a balanced water budget where the inputs match the outputs:

inputs (irrigation + precipitation) = outputs (runoff + internal drainage + ET)

Evapotranspiration (ET) is a combination of the physical process of evaporation and the biological use of water by plants, known as transpiration. These two processes are tied together in their response to climate factors. So as long as irrigation inputs are not applied in sufficient volume to cause surface runoff or deep infiltration (past the root zone) losses, efficient irrigation scheduling boils down to replacing only the amount of water lost to ET:

irrigation = ET

How can technology help turf irrigators conserve water? If we can directly measure the moisture status of the soil using sensors, or indirectly measure soil moisture loss via ET estimation, we know exactly how much irrigation to apply. Because of cost, reliability and soil variability, moisture sensors are rarely used to direct irrigation of turfgrass. However, the rising operating costs of irrigation, along with the availability of affordable technological advances in electronic circuitry, software and wireless communications, are making soil moisture sensors a viable component of future irrigation management BMPs.

In contrast to soil sensors, simplified ET estimators have seen widespread use as aids in scheduling turf irrigation. Many irrigation management software programs currently in use at golf courses and athletic fields have an ET feature which predicts water loss and automatically controls how much water is delivered.

Although all ET equations provide estimates based on climate factors, they are not all equally applicable to turf situations. FAO 56, derived from the Penman-Monteith equation, is the current standard for ET estimation in cropping systems adopted by the Food and Agriculture Organization of the United Nations (Allen et. al., 1998) and was selected for use in this study.

Materials and methods

During 2003 and 2004, experiments were conducted at the University of Minnesota on a California-style sand creeping bentgrass green. Our objectives were threefold:

1. Evaluate the response of ECH_2O capacitance sensors to changes in soil moisture by applying various daily irrigation treatments (ECH_2O is Decagon's product name for its environmental capacitance product.)

a) 100-percent replacement of lysimeter-indicated ET loss (control);

b) 100-percent replacement of FAO 56 estimated ET loss; and

c) 80-percent replacement of FAO 56 estimated ET loss.

2. Evaluate the accuracy of FAO 56 ET estimation (theoretical loss) by comparing against weighing lysimetry (actual loss).

3. Develop FAO 56 crop coefficients for creeping bentgrass turf in Minnesota.

The green was divided into six 15-foot by 15-foot plots, each of which had the following installed:

Weighing lysimeter: A 5-gallon bucket containing soil and turf that was flush with the surrounding surface and could be removed from the green and weighed. The lysimeter gained weight after irrigation or precipitation events, and lost weight slowly throughout the day as a

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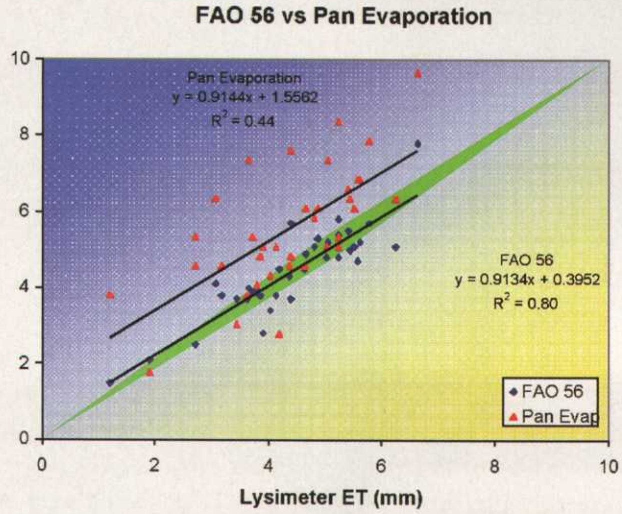
FIGURE 1



Comparison of FAO 56 and pan evaporation ET estimates against lysimeter measured ET over the four experimental periods. The green line signifies lysimeter ET.

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result of ET loss. Lysimeter weight change was converted to a depth of water lost or gained in millimeters (mm) (Aronson et. al., 1987), and accounting for any internal drainage, weight loss over a 24-hour period was accepted as the actual ET loss in mm/day for each plot.

Five ECH_2O 20 centimeter (cm) sensors were inserted horizontally into the soil at 2-, 4-, 6-, 8- and 10-inch (5-, 10-, 15-, 20- and 25-cm) depths, which allowed tracking of the wetting front by depth. The sensor cables, connected to data loggers off the putting green, were buried to allow normal maintenance practices.

Independent irrigation: Each plot had a separate station on the LTC controller used to irrigate the plots. Individual plot irrigation uniformity ranged from 70 percent to 90 percent throughout each study period.

Climate data, including hourly averages of solar radiation, temperature, humidity and wind speed were downloaded daily from an onsite weather station and entered into software to generate FAO 56 ET estimates. The six plots were randomly divided into three replications of two irrigation treatments for each of a series of four 10-day experiments.

Turf quality on each of the six plots was rated four times per experiment on a 0-9 scale with 0 being dead turf, 6 being minimally acceptable, and 9 being ideal. Data was statistically analyzed using the multivariate analysis and repeated measure functions in SAS (SAS Institute, 1998).

Results

Turf quality was not significantly different between treatments in any of the experiments.

Comparing pan evaporation and FAO 56 ET estimates to lysimeter ET over the two-year study period shows a strong relationship between FAO 56 estimated ET and lysimeter ET (R^2=0.80). Trend lines reveal that pan evaporation consistently overestimates actual ET, while FAO 56 appears to overestimate ET on low loss days and underestimate ET on high loss days. (Figure 1)

ECH_2O sensors recognized changes in soil moisture because of the irrigation treatments (Figure 2). ECH_2O probe sensitivity was high with extremely low variation in individual sensor response. All 30 of the originally installed sensors have performed without failure for at least two full years.

Sensor data indicates temporal trends which vary with depth and treatment. Daily replacement of 100 percent of lysimeter ET seems to maintain consistent soil moisture at the 5- and 10-cm depths over a 10-day period, with a slight downward trend at 15 cm. Daily replacement of 80 percent of FAO 56 ET seems to maintain consistent soil moisture at the 5 cm depth over a 10-day period, with slight downward trends at 10 cm and 15 cm, which indicates a difference in wetting depth between the two treatments.

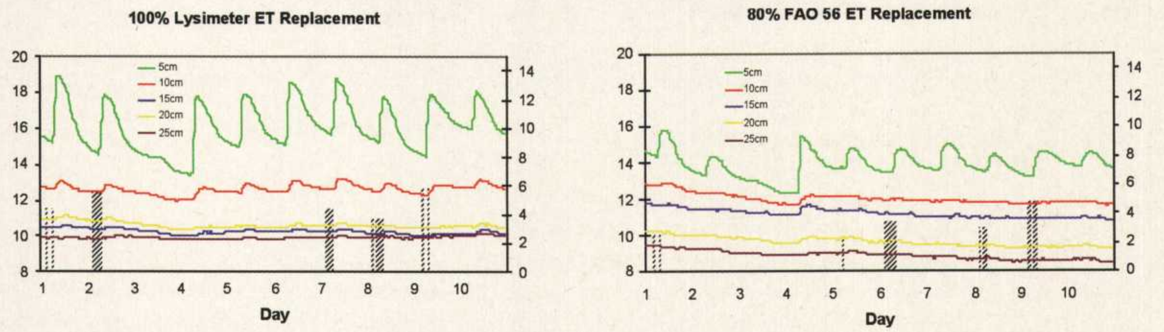
This research indicates that Decagon ECH_2O capacitance sensors are sensitive and accurate enough to aid in efficiently delivering irrigation to managed turfgrass. These sensors could also be integrated into a feedback loop with future irrigation management software programs (Bremer, 2003).

FAO 56 ET estimation also shows great promise in maximizing irrigation scheduling efficiency using readily available climate data. Some current irrigation management software using other forms of ET estimation with varying success have been met with skepticism by many turf managers; FAO 56 represents an excellent opportunity to incorporate accurate ET estimation into irrigation scheduling by a broad range of end users from homeowners to superintendents.

Both of these technologies have the potential to serve as the foundation for future automated irrigation management, which can conserve water resources while maintaining turf quality.

Sensor data and turf quality ratings from the

FIGURE 2



Comparison of sensor response at 5-, 10-, 15-, 20- and 25-centimeter depth over a 10-day period for the two treatments in experiment two. Irrigation input shown in background bar graph. Note: Irrigation on day three was cancelled due to high winds and made up on day four.

project indicate that irrigation which replaces 80 percent of estimated ET is sufficient to maintain turf quality. Deficit irrigation has great potential in conserving water resources in areas where rainfall occurs regularly since low irrigation volumes could be used to simply maintain minimum soil moisture levels between rain events which would recharge the rootzone.

One additional point of interest generated by this project is the depth of soil wetting under daily irrigation. The sensor data indicated that under daily irrigation replacement of lysimeter indicated ET loss, the soil is wetted to no deeper than 4 inches. This discovery seems to validate the adage that watering deeply and infrequently results in deeper rooting and uses less water than watering daily. However, keep in mind that, as dictated by their annual lifecycles, the rooting depth of cool-season grasses peaks in the fall and spring and recedes during the summer.

To settle the deep-and-infrequent vs. shallow-and-frequent debate, perhaps the best solution is a compromise: water deep and infrequently during the spring and fall when roots are at their deepest and water daily with smaller volumes during the summer stress periods when roots are most shallow. Any irrigation which goes deeper than the rootzone becomes an infiltration loss and represents wasted water. Know where roots are located.

ET estimation and *in situ* sensing are only two of many technologies being evaluated for water conservation in turfgrass culture. Other advances include but are not limited to:

- progress in plant breeding for low water use and drought tolerance;
- soil management and root zone construction;
- use of effluent, saline, and other non-potable water sources;
- subsurface irrigation;
- technological improvements in water delivery efficiency and uniformity; and
- continued research in deficit irrigation scheduling.

All of the above, along with ET estimation and sensing technology, gives superintendents and turf managers the decision-making criteria and flexibility to respond to the evolving water crisis and make management of turfgrass sustainable and profitable well into the 21st century.

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