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Measurement of Evapotranspiration in Turfgrass: Recommended Techniques and Adjustment Coefficients

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Summary. Evapotranspiration (ET) from turfgrass can be measured directly using lysimeters (LYS), estimated from weather data using models, or approximated using atmometers. Evapotranspiration measurements from LYS were compared with ET estimates from four variations of the American Society of Civil Engineers (ASCE) standardized ET equation including the use of: 1) hourly steps of measured net radiation (R_n) ($ASCE_{HM}$); 2) hourly steps of R_n calculated from global irradiance ($ASCE_{HC}$); 3) daily steps of measured R_n ($ASCE_{DM}$); and 4) daily steps of R_n calculated from global irradiance ($ASCE_{DC}$); ET from LYS was also compared with the Priestley-Taylor (PT) model and atmometers. All collections were from a sward of tall fescue (*Schedonorus arundinaceus* Schreb.) turfgrass at the Rocky Ford Turfgrass Research Center, Manhattan, KS. Results indicate the $ASCE_{DC}$ could improve irrigation scheduling in turfgrass by providing accurate ET estimates from standard weather station data where measured R_n is not available. Adjustment factors for several of the methods are recommended below.

Rationale. Turfgrass in the United States is estimated to cover 40 to 50 million acres, an area three times larger than any irrigated crop. However, many homeowners do not understand how to tailor irrigation to their lawn and climate (Bremer et al., 2012, 2013, and 2015). A better understanding of turfgrass irrigation requirements (i.e., ET) would help city planners, water distribution districts, and homeowners to manage their irrigation water more efficiently and reduce the demand for water, especially during drought. Several techniques are available to measure or estimate ET. To

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our knowledge, no research has compared ET data obtained from these techniques simultaneously and side-by-side. Such a comparison would be invaluable in demonstrating their performance relative to each other when placed in the same environment.

Objectives. To compare measurements of ET from microlysimeters (Bremer, 2003) with ET estimates from several techniques (previously listed) at the same site, including the ASCE-PM and PT models as well as atmometers (Peterson et al., 2015).

Study Description. This investigation started in July 2010 at the Rocky Ford Turfgrass Research Center at Manhattan, KS, and continued during the growing seasons of 2011 and 2012. Data were collected on precipitation-free days from July through October 2010, May through August 2011, and June through October 2012, and analyzed by periods with high ET, low ET, and pooled across all days. The study was conducted in a sward (>0.6 acre) of tall fescue turfgrass mowed at 4 inches, within an area of ~8 acres of mostly irrigated turfgrass (Figure 1). Soil type was a silty clay loam. For more information see Peterson et al. (2017).

Results. Overall, mean ET on measurement days (May to October) ranged from 0.22 (LYS) to 0.18 in./d ($ASCE_{HC}$) (Table 1). During days with high evaporative demand, ET from daily-step models ($ASCE_{DM}$, $ASCE_{DC}$) were equivalent to LYS, based on paired t-tests. Similarity in ET among LYS, $ASCE_{DM}$, and $ASCE_{DC}$ indicate using R_n calculated from global irradiance is sufficient in the daily-step model in the absence of measured R_n. At high ET rates, ET from $ASCE_{HM}$ and PT were 9 and 5% lower than LYS, respectively, but accuracy was significantly reduced (by 22%) with $ASCE_{HC}$ (Table 1 and Figure 2). Atmometer ET averaged 17% lower than LYS, but performance was better at low than at high ET rates. Under environmental conditions similar to this study, the following adjustment factors are recommended across all values of ET for tall fescue turfgrass: (atmometer ET)/0.83, ($ASCE_{HC}$ ET)/0.80, and ($ASCE_{HM}$ ET)/0.92. Adjustment for the PT is recommended only at high ET rates, (PT ET)/0.95.

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Table 1. Comparisons of evapotranspiration (ET) means between lysimeters (LYS ET) and other measurement or estimation techniques

Measurement technique	n	Mean ET	RMSE†	MBE‡	%E§	d¶	p#
		------------- in./d -------------					
Lysimeter	78	0.22					
ASCE$_{HM}$††	78	0.20	0.039	-0.017	-4.7	0.93	***
ASCE$_{HC}$‡‡	78	0.18	0.064	-0.044	-15.6	0.82	***
ASCE$_{DM}$§§	78	0.22	0.037	-0.004	1.0	0.94	NS
ASCE$_{DC}$¶¶	78	0.22	0.048	-0.002	5.0	0.90	NS
PT##	78	0.21	0.043	-0.005	1.9	0.92	NS
Atmometer	78	0.18	0.058	-0.038	-15.0	0.87	***

LYS ET > 0.22 in./d

Measurement technique	n	Mean ET	RMSE†	MBE‡	%E§	d¶	p#
		------------- in./d -------------					
Lysimeter	42	0.28					
ASCE$_{HM}$††	42	0.26	0.042	-0.024	-8.3	0.80	***
ASCE$_{HC}$‡‡	42	0.22	0.078	-0.062	-22.0	0.55	***
ASCE$_{DM}$§§	42	0.27	0.040	-0.007	-2.2	0.82	NS
ASCE$_{DC}$¶¶	42	0.27	0.056	-0.011	-3.8	0.71	NS
PT##	42	0.27	0.042	-0.015	-4.4	0.70	*
Atmometer	42	0.23	0.067	-0.052	-18.2	0.62	***

LYS ET < 0.22 in./d

Measurement technique	n	Mean ET	RMSE†	MBE‡	%E§	d¶	p#
		------------- in./d -------------					
Lysimeter	36	0.15					
ASCE$_{HM}$††	36	0.14	0.034	-0.008	-0.5	0.83	NS
ASCE$_{HC}$‡‡	36	0.13	0.044	-0.022	-8.0	0.70	***
ASCE$_{DM}$§§	36	0.15	0.035	-0.001	4.7	0.82	NS
ASCE$_{DC}$¶¶	36	0.16	0.038	0.009	15.2	0.77	NS
PT##	36	0.15	0.043	0.006	9.3	0.79	NS
Atmometer	36	0.13	0.044	-0.022	-10.7	0.74	**

Data were compared across all days (top) and on days with high ET (middle) and low ET (bottom) (i.e., above and below the average LYS ET of 0.22 in./d).

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† Root mean square error, calculated as: $RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(ET_i - LYS_i\right)^2}$.

‡ Mean bias error, calculated as: $MBE = \frac{1}{n}\sum_{i=1}^{n}\left(ET_i - LYS_i\right)$.

§ Mean percent error, calculated as: $\%E = \sum\left(\frac{ET_i - LYS_i}{LYS_i}\right)\times 100$.

¶ Index of agreement, calculated as: $d = 1 - \left[\frac{\sum_{i=1}^{n}\left(ET_i - LYS_i\right)^2}{\sum_{i=1}^{n}\left[\left|ET_i - \overline{LYS}\right| + \left|LYS_i - \overline{LYS}\right|\right]^2}\right]$.

Probability that ET_x and Lysimeter ET are significantly different from each other based on paired t-test at $P < 0.05$.
†† American Society of Civil Engineers (ASCE) standardized ET equation using hourly steps from measured net radiation (R_n).
‡‡ ASCE standardized ET equation using hourly steps from R_n calculated from global irradiance.
§§ ASCE standardized ET equation using daily steps from measured R_n.
¶¶ ASCE standardized ET equation using daily steps from R_n calculated from global irradiance.
Priestley-Taylor model.
*** Indicates significant difference at $P < 0.001$.
** Indicates significant difference at $P < 0.01$.
* Indicates significant difference at $P < 0.05$.

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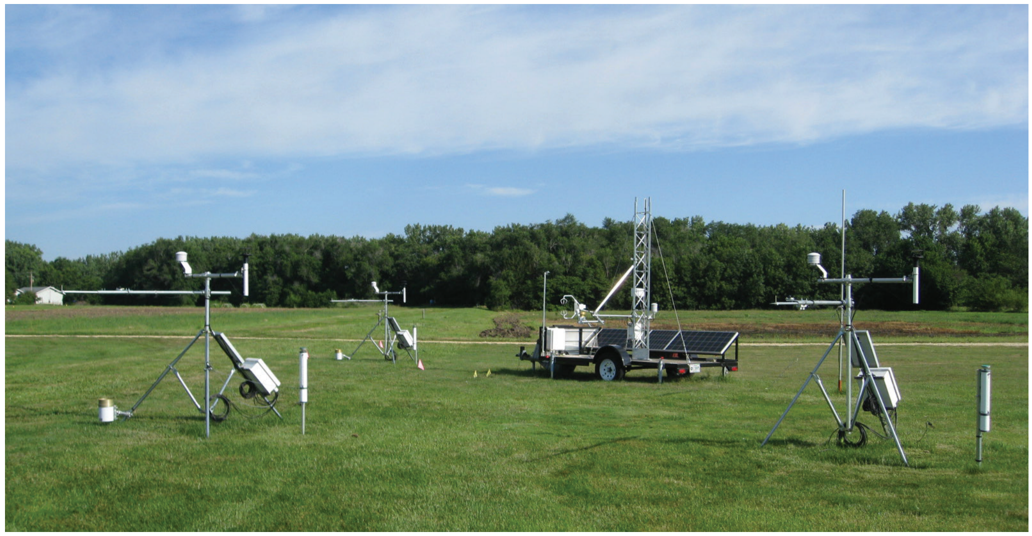

Figure 1. Array of instrumentation used at Rocky Ford Turfgrass Research Center, Manhattan, KS, to measure evapotranspiration using the various methods. Lysimeters were installed in the ground in the footprint area of the weather stations.

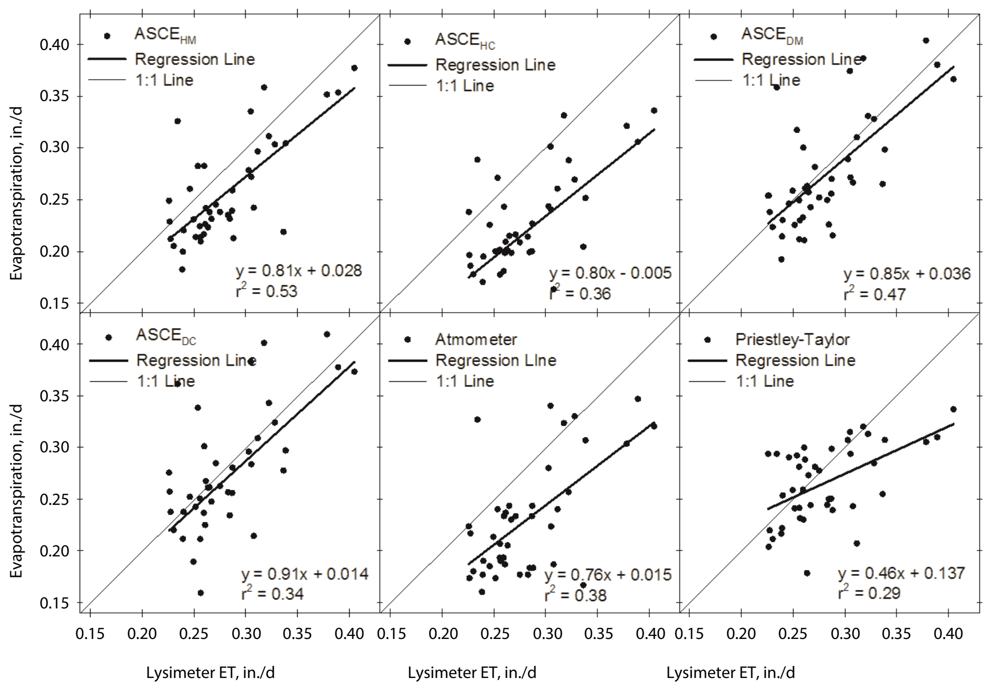

Figure 2. Comparison of the various evapotranspiration (ET) measurement or modeling techniques to lysimeter-measured ET at high ET rates (i.e., when lysimeter ET was greater than 0.22 in./d) (n = 42).

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