Evapotranspiration of Cool-Season Turfgrasses in the Humid Northeast[1]

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ABSTRACT

As competition for water increases in the northeastern United States, turfgrass culture must be directed toward practices that will lower water requirements. This study was conducted to quantify and compare the evapotranspiration (ET) rate of well-watered grasses in the humid Northeast. Predictive methods for irrigation scheduling of turf were also evaluated. Weighing lysimeters, 0.25 m in diameter and 0.28 m deep, were placed into field plots of well-watered mature turf growing on an Enfield silt loam (coarse-silty over sandy-skeletal, mixed, mesic Typic Dystrocrept), and ET was determined by weighing the lysimeters at 24-h intervals throughout the summers of 1984 and 1985. The grasses studied were: *Poa pratensis* L., 'Baron' and 'Enmundi'; *Lolium perenne* L., 'Yorktown II'; *Festuca rubra* var. *commutata* Gaud., 'Jamestown'; and *Festuca ovina* var. *duriuscula* (L.) Koch, 'Tournament'. Consistent annual differences were not observed in the variable summer weather that characterizes southern New England. Daily meteorological data were used to calculate reference ET by the modified Penman equation and from pan evaporation. A crop coefficient (Kc) was calculated for each grass as the ratio of ET measured to ET predicted. Seasonal Kc values based on the Penman equation ranged from 0.88 for Tournament in 1984, to 1.09 for Enmundi in 1985 (CV, 0.15–0.30). Seasonal Kc based on pan evaporation data was more variable, ranging from 0.86 to 1.31 (CV, 0.34–0.44). The Penman equation predicted ET more consistently, and could provide a reliable and useful tool for irrigation scheduling of turfgrass in southern New England.

Additional index words: ***Festuca ovina*** **var.** ***duriuscula*** **(L.) Koch.,** ***Festuca rubra*** **var.** ***commutata*** **Gaud.,** ***Lolium perenne*** **L.,** ***Poa pratensis*** **L., Crop coefficient, Water use, Lysimeter.**

TURFGRASS maintenance can require considerable irrigation water, even in the humid northeastern United States. Turfgrass culture must be directed toward practices that will lower water requirements as competition for water use increases.

Transpiration accounts for most of the water lost from a dense turfgrass canopy (Beard, 1973). It has been established that transpiration rate varies among well-watered turfgrass species (Beard, 1973; Beard, 1986; Doss et al., 1964; Partridge, 1941; Peterson, 1985). Despite the growing attention being focused on turf water use, little research has been directed toward measuring water consumption by the cool-season grasses growing in the Northeast. Drought conditions occur periodically in the Northeast during most growing seasons, and restrictions on water availability for turf irrigation are no longer isolated to the arid regions of the country. Knowledge of water use rates of turfgrasses is necessary to identify grasses with lower water requirements, and to design and utilize irrigation systems for maximum water use efficiency.

Methods that predict crop water use on the basis of climatic conditions are used frequently for irrigation scheduling because accurate field measurements are difficult to obtain. These methods predict the water use of a standardized reference crop (ETo), which is defined as "the rate of evapotranspiration from an extensive surface of 80 to 150 mm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water" (Doorenbos & Pruitt, 1977). Crop coefficients (Kc) are used to adjust this value for specific crop and climatic conditions (Doorenbos & Pruitt, 1977).

The goal of this study was to quantify and compare water use by four species of cool-season turfgrasses maintained under well-watered conditions. Crop coefficients for each grass were computed from these data based on two predictive methods (the modified Penman equation and pan evaporation). The variability of each method was evaluated to determine its reliability for predicting evapotranspiration (ET) in the variable climate of the Northeast.

MATERIALS AND METHODS

Evapotranspiration of four species (five cultivars) of cool-season turfgrasses was measured during two seasons under well-watered conditions (soil water potential greater than −40 kPa). Evapotranspiration rates were measured by determining the mass loss of weighing lysimeters containing 0.15-m-deep undisturbed sod-soil cores taken from turf swards established in 1980. Four replicate lysimeters were constructed using the following grasses: Kentucky bluegrass (*Poa pratensis* L., 'Baron' and 'Enmundi'), perennial ryegrass (*Lolium perenne* L., 'Yorktown II'), chewings red fescue (*Festuca rubra* var. *commutata* Gaud., 'Jamestown'), and hard fescue (*Festuca ovina* var. *duriuscula* (L.) Koch, 'Tournament').

The plots were established at the Turfgrass Research Farm of the University of Rhode Island Agricultural Experiment Station (AES). The latitude and longitude of the site are 41.30°N and 71.30°W, respectively. The soil is an Enfield silt loam (coarse-silty over sandy-skeletal, mixed, mesic Typic Dystrochrept). In 1984, each lysimeter was placed at ground level in a 1.8- by 2.4-m field plot of the same species that had been established at the same time as the turf from which the lysimeter cores were taken. In this way, edge effects were avoided. In 1985, the lysimeters containing the same sod as in 1984 were placed in the center of 6.7- by 7.6-m plots.

The lysimeters were patterned after those used by Feldhake et al. (1983) to study turfgrass ET. Each lysimeter was 0.245 m in diameter and 0.28 m deep, and each contained a 0.15-m-deep undisturbed sod and soil core resting on 0.08 m of a 1:1, native soil/perlite mixture. The 0.15-m depth of the sod-soil core was observed to include the entire turf root system. The grass in each lysimeter was mowed to a height of 50 mm every 3 days. Stand density and visual quality were maintained at acceptable levels for all grasses throughout the experiment.

To maintain well-watered conditions, the lysimeters and the surrounding plots were sprinkler irrigated to saturation and permitted to drain to field capacity (i.e., no additional drainage), which was reached in approximately 24 h. Plots were irrigated every 4 to 5 days in the absence of precipitation. An additional lysimeter of each turfgrass containing a tensiometer installed at a depth of 0.10 m was monitored to ensure that the above irrigation procedure maintained the soil water potential at more than −40 kPa.

The lysimeters were weighed at 24-h intervals to determine water loss due to ET. The balance used (20-kg solution balance manufactured by O'Haus Scale Corp., Florham Park, NJ) provided accuracy to the nearest gram (equivalent to

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0.02 mm of water). Because the study was performed under field conditions, data were not obtained on any day when precipitation occurred. The lysimeters were permitted to drain for 24 h before measurements were restarted. In 1984, 35 24-h measurements were obtained from each of the 20 lysimeters, while 40 24-h measurements were obtained from each lysimeter in 1985.

Predictive Methods

Two predictive methods, the modified Penman equation and pan evaporation, were used to compute reference ET and were evaluated for their predictive consistency. A crop coefficient (Kc) was calculated from both methods as the ratio between actual ET (ETa) and predicted ET (ETo), as:

$$\mathrm{Kc} = \mathrm{ETa}/\mathrm{ETo}\,. \qquad [1]$$

The modified Penman equation (Burman et al., 1980; Penman, 1948) combines an energy balance and an aerodynamic term. The exact form of the equation used was:

$$\mathrm{ETo} = \frac{\Delta}{\Delta + \gamma}(\mathrm{Rn} + G) + \frac{\gamma}{\Delta + \gamma}\, 15.36\ \mathrm{wf}\,(ea - ed)\,. \qquad [2]$$

where ETo = reference crop ET in J $\mathrm{m}^{-2}\mathrm{day}^{-1}$; Δ is the slope of the vapor pressure − temperature curve in kPa/°C; γ is the psychometer constant in kPa/°C; Rn is net radiation in J $\mathrm{m}^{-2}\mathrm{day}^{-1}$; G is soil heat flux to the soil in J $\mathrm{m}^{-2}\mathrm{day}^{-1}$ (assumed to be zero on a daily basis); wf is the wind function (dimensionless); and $(ea - ed)$ is the mean daily vapor pressure deficit in kPa.

The slope, Δ, was approximated from mean daily temperature [(Tmax − Tmin)/2] (Bosen, 1960). The constant, γ, was calculated from average barometric pressure (KPa), a function of elevation above sea level, and the latent heat of vaporization (J g^{-1}) that was computed from mean daily temperature (Brunt, 1952). The wind function (wf) (Schwab et al., 1981) used was:

$$\mathrm{wf} = 1.0 + 0.00621\ (U_2)\,, \qquad [3]$$

where U_2 is the wind velocity (Km day^{-1}) at a height of 2 m. Wind velocity was measured at a 0.5-m height. To extrapolate the data to the wind velocity at 2 m, the expression from Burman et al. (1980) was used:

$$U_2 = U_z\,(2/z)^{0.2}\,, \qquad [4]$$

where z (m) is the elevation of the wind measurement, and U_z is the wind velocity at elevation z (0.5 m). The saturation vapor pressure at daily mean air temperature (Tmax − Tmin/2) was used for ea, and the saturation vapor pressure at the mean daily dewpoint temperature was used for the ambient mean daily vapor pressure, ed.

Based on the work of Merva and Fernandez (1985) dewpoint temperature was set equal to the daily minimum temperature. Saturation vapor pressure (kPa) at the dewpoint temperature (ea) and mean daily temperature (ed) was computed from the approximation of Bosen (1960) as reported in Burman et al. (1980), where the saturation vapor pressure (e) for any temperature was calculated as

$$e = 33.8639\,[(0.00738\mathrm{T} + 0.8072)^8 - 0.000019|1.8\mathrm{T} + 48| + 0.001316]\,, \qquad [5]$$

where T is the temperature of interest in °C. Net radiation was calculated from the expression of Schwab et al. (1981):

$$\mathrm{R_n} = (1 - r)\mathrm{R_s} - \sigma \mathrm{T_a^4}\,(0.56 - 0.08\sqrt{ed})\,(0.10 + 0.9n/N)\,, \qquad [6]$$

where r = albedo, $\mathrm{R_s}$ is incoming solar radiation (J $\mathrm{m}^{-2}\mathrm{day}^{-1}$), $\mathrm{T_a}$ is the mean daily air temperature (°K), σ is the Stefan-Boltzmann constant, and n/N is the ratio of actual to possible hours of sunshine. Daily records of incoming solar radiation were coupled with extraterrestrial radiation to obtain estimates of n/N (Penman, 1948).

Solar radiation data, derived from a standard pyranometer, were provided by the Eppley Laboratory in Newport, RI, located 20 km from the plot area. Extraterrestrial radiation values for each month were obtained for latitude 40°N (Doorenbos and Pruitt, 1977). Wind speed, maximum temperature, and minimum temperature were collected daily from the Rhode Island AES weather station located 200 m from the experimental plots. A standardized albedo value of 0.23 and an elevation of 50 m above sea level were used in all calculations.

The pan evaporation method is based on the assumption that evaporation from a specific open-water surface provides a standard measurement of the combined effect of temperature, radiation, wind, and humidity, which can be used to predict crop water use. Evaporative loss from a standard Weather Bureau Class A pan (Epan) is related to reference crop ET (ETo) by an empirically derived coefficient (Kp) (Doorenbos and Pruitt, 1977):

$$\mathrm{ETo} = \mathrm{Kp} \times \mathrm{Epan}\,. \qquad [7]$$

Burman et al. (1980) present a range of Kp values to be used with varying environmental conditions including pan exposure, wind velocity, and distance of homogenous material to the windward side.

The evaporation pan used to compute ETo in this study was surrounded by actively growing, well-watered grass extending approximately 100 m in all directions. The Kp values used in this study were selected from the following values given by Doorenboos and Pruitt (1977):

Wind —km day^{-1}—	Mean relative humidity —%—		
	low <40	*medium* 40–70	*high* >70
Light (<175)	0.7	0.8	0.85
Moderate (175–425)	0.65	0.75	0.8

All the data were subjected to an analysis of variance for a completely randomized design using a general linear models procedure (SAS Institute, 1982). Because dates are not randomly assigned within species, date was used as a subplot observation, rather than a replication, in the statistical analysis.

RESULTS AND DISCUSSION

Actual Evapotranspiration

Mean ET of all the grasses included in this study was 3.6 mm water day^{-1} (25 mm week^{-1}) during the months of July through September. These values ranged from a minimum of 1.22 mm water day^{-1} for hard fescue in September, to a maximum of 7.48 mm water day^{-1} for Kentucky bluegrass (cv. Enmundi) in July. This is consistent with previously reported ET rates for cool-season turfgrasses, which range between 2.6 and 7.6 mm day^{-1} (Beard, 1973; Doss et al., 1964; Quackenbush and Phelan, 1965) although rates in excess of 11.4 mm day^{-1} occur occasionally in hotter, less humid climates (Beard, 1973; Beard, 1986; Peterson, 1985).

Table 1 contains mean daily water use rates during

Table 1. Mean daily evapotranspiration (ET) rates of five cool-season turfgrasses maintained in well-watered conditions in 1984 and 1985 (field study).

Species	Mean daily ET 1984	Mean daily ET 1985
	mm water	
Kentucky bluegrass, cv. Baron	3.50a†	3.65c
Kentucky bluegrass, cv. Enmundi	3.38b	4.14a
Red fescue	3.38b	3.58d
Perennial ryegrass	3.40b	3.96b
Hard fescue	2.25c	3.93b

† Means in a column followed by the same letter are not significantly different at the 5% level based on Duncan's Multiple Range Test.

Table 2. Monthly precipitation (mm water) and departure from the norm in Kingston, RI, in 1984 and 1985.

Month	1984	1985
July	178.6 (+102.6)	73.9 (−2.0)
August	27.7 (−85.6)	322.8 (+209.6)†
September	55.9 (−53.1)	69.9 (−34.5)
Total	262.2 (−36.1)	466.6 (+173.1)

† The majority of this precipitation occurred in a few intense storms concentrated at the end of the month.

1984 and 1985. In 1984, the Kentucky bluegrass cultivar, Baron, had significantly higher ET rates than the other grasses, while the hard fescue cultivar used significantly less water than the other grasses. Both of these cultivars ranked intermediate in 1985. The red fescue cultivar, Jamestown, had ET rates comparable to Enmundi and the perennial ryegrass cultivar, Yorktown II, in 1984, but used the least water of all the grasses tested in 1985.

Differences in water use rates between Kentucky bluegrass cultivars also have been reported by Schmidt and Everton (1985) and by Shearman and Beard (1973). Although the two Kentucky bluegrass cultivars, Baron and Enmundi, differed significantly in water use rates during each season, their rank was reversed from 1984 to 1985. In 1984, Baron used significantly more water than any of the other grasses, while Enmundi ranked intermediate relative to the water use of the other grasses. Enmundi used significantly more water than the other grasses in 1985.

When soil water is readily available, turfgrass water use is usually assumed to be governed primarily by conditions external to the plant (Doss et al., 1964; Lemon et al., 1957; Tovey et al., 1969). Reports on turfgrass ET under well-watered conditions have concluded that ET is a function of meteorologic conditions and the extent of vegetative cover (Doss et al., 1964; Feldhake et al., 1983). Our data support these conclusions. Based on our actual ET measurements, all five grasses used more water in 1985 than in 1984. The annual differences may have been due in part to climatic variations. Humidity and cloudiness, which are inversely related to evaporative demand, were much higher in July 1984 than in July 1985. Pan evaporation was 11% greater during July and August of 1985 than during the comparable period in 1984. Table 2 contains monthly precipitation in 1984 and 1985. Table 3 contains additional climatic data on a biweekly basis for the experimental period.

The results of our study do not demonstrate dramatic, consistent differences in ET rates between well-watered, cool-season turfgrasses. Relative rankings differed appreciably between years. Southern New England is characterized by wide variations in summer temperature, cloudiness, and humidity. The data suggest that the grasses may respond differently as climatic conditions change. In a study of ET from several species of well-watered, cool-season turfgrasses, Sheffer (1979) found that relative rank was affected by climatic conditions. At moderate levels of humidity, perennial ryegrass exhibited greater ET rates than tall fescue and Kentucky bluegrass, while at higher humidities tall fescue used less water than either Kentucky bluegrass or perennial ryegrass.

Predicted Evapotranspiration

For the modified Penman equation method, average seasonal crop coefficients (Kc) (Table 4) ranged from 0.88 for hard fescue in 1984, to 1.09 for Enmundi

Table 3. Mean maximum air temperature, mean daily solar radiation, and mean wind speed in Kingston, RI, in 1984 and 1985.

Period†	Mean max. air temp. 1984	Mean max. air temp. 1985	Mean solar radiation 1984	Mean solar radiation 1985
	°C		MJ m^{-2} day^{-1}	
Early July	27.5	26.2	21.2	19.0
Late July	29.2	28.8	19.9	24.9
Early Aug.	28.1	29.2	14.1	17.8
Late Aug.	27.4	21.8	14.7	13.8
Early Sept.	22.7	--‡	19.2	--
Late Sept.	23.6	26.0	17.0	13.2
	Mean wind speed		Relative humidity	
	km day^{-1}		%	
Early July	93.1	67.5	61	66
Late July	66.4	63.0	68	60
Early Aug.	68.3	56.3	74	68
Late Aug.	96.0	50.6	75	66
Early Sept.	52.5	--	62	--
Late Sept.	78.1	72.3	55	65

† Mean values are based on only days that ET measurements were obtained.
‡ No ET measurements taken.

Table 4. Average biweekly seasonal crop coefficients (Kc) for five cool-season turfgrasses in 1984 and 1985, based on the Penman equation.

Species	Early July	Late July	Early Aug.	Late Aug.	Early Sept.	Late Sept.	Seasonal mean	Seasonal CV
1984								
KBb§	0.92a†	1.02a	0.93a	0.91a	1.23a	1.09a	1.02a	0.15
KBe	0.88a	0.97a	0.88a	0.91a	1.21a	1.10a	1.01b	0.15
RF	0.87a	0.96a	0.87a	0.87a	1.18a	1.11a	1.00b	0.15
PR	0.89a	0.98a	0.90a	0.90a	1.20a	1.12a	1.01b	0.15
HF	0.80b	0.82b	0.77b	0.72b	1.01b	0.95b	0.88c	0.18
1985								
KBb	1.09a	1.07a	0.74c	0.78c	--‡	0.83c	0.97c	0.30
KBe	1.17a	1.22a	0.89a	0.96a	--	0.95a	1.09a	0.28
RF	1.04a	1.03b	0.75c	0.84bc	--	0.84a	0.95d	0.28
PR	1.14a	1.17a	0.83b	0.90ab	--	0.87b	1.05b	0.29
HF	1.14a	1.15a	0.83b	0.87abc	--	0.89b	1.04b	0.28

† Means in a column for each year followed by the same letter are not significantly different at the 5% level based on Duncan's Multiple Range Test.
‡ No data were collected in early September of 1985 due to frequent precipitation.
§ KBb = Kentucky bluegrass, cv. Baron; KBe = Kentucky bluegrass, cv. Enmundi; RF = red fescue; PR = perennial ryegrass; and HF = hard fescue.

Table 5. Average biweekly seasonal crop coefficients (Kc pan) for five cool-season turfgrasses in 1984 and 1985, based on the pan evaporation method.

Species	Early July	Late July	Early Aug.	Late Aug.	Early Sept.	Late Sept.	Seasonal mean	Seasonal CV
				1984				
KBb§	0.76a†	1.01a	1.51a	0.86a	1.17a	0.89a	1.03a	0.35
KBe	0.72a	0.97a	1.43a	0.86a	1.16a	0.90a	1.01b	0.35
RF	0.78a	0.95a	1.42a	0.82a	1.14a	0.91a	0.95b	0.34
PR	0.72a	0.98a	1.47a	0.86a	1.14a	0.92a	1.02b	0.34
HF	0.68b	0.83b	1.26b	0.68b	0.95b	0.78b	0.86c	0.38
Kp	0.80	0.81	0.84	0.83	0.82	0.81	0.82	0.02
Pan ET (mm day^{-1})	4.5	5.3	3.3	3.8	3.8	3.8	4.0	0.18
				1985				
KBb	1.30a	1.16a	0.94c	1.09a	--‡	0.91a	1.15b	0.43
KBe	1.41a	1.33a	1.13a	1.35a	--	1.04a	1.31a	0.43
RF	1.24a	1.12a	0.95c	1.17a	--	0.90a	1.13b	0.42
PR	1.37a	1.27a	1.05b	1.26a	--	0.96a	1.25ab	0.43
HF	1.38a	1.25a	1.04b	1.22a	--	0.97a	1.24ab	0.44
Kp	0.82	0.80	0.83	0.84	--	0.83	0.82	0.02
Pan ET (mm day^{-1})	4.5	5.6	4.1	2.3	--	3.6	4.2	0.30

† Means in a column for each year followed by the same letter are not significantly different at the 5% level based on Duncan's Multiple Range Test.

‡ No data were collected in early September of 1985 due to frequent precipitation.

§ See Table 4 for definition of abbreviations.

Kentucky bluegrass in 1985. Coefficients of variation for the 1984 Kc values ranged from 0.15 to 0.18. Somewhat greater variability occurred in 1985, with coefficients of variation ranging from 0.28 to 0.30. These values indicate a consistent relationship between ET predicted by the Penman equation and actual ET rates of the five grasses.

Differences in Kc between grasses were not as pronounced as differences in actual ET rates due to the changing relationship of predicted to actual ET among the grasses. For the total period of observation, the mean crop coefficients ranged from 0.97 for hard fescue to 1.05 for Baron Kentucky bluegrass.

When the individual Kc values were grouped and analyzed on a biweekly basis (Table 4), more variation between observed and predicted values was revealed. In 1984, there was a general trend for over-prediction in July to under-prediction in September. This trend is reversed in the 1985 analysis. The biweekly Kc values for all species ranged from 0.72 to 1.23. Given the average ET rate of 3.6 mm day^{-1} (50 mm 2 weeks^{-1}) found in this study, the variation from a Kc of 1.0 represents a maximum deficit of 11 to 14 mm water transpired over a 2-week period.

The pan coefficient (Kp) selected from the criteria of Doorenboos and Pruitt (1977) averaged 0.82 both years (Table 5), since light wind conditions and moderate humidity prevailed. Seasonal crop coefficients derived by the pan evaporation method (Kc pan) in 1984 and 1985 (Table 5) were found to be more variable than those derived by the Penman equation. Seasonal Kc pan means ranged from 0.86 to 1.31. In 1984, Kc pan coefficients of variation ranged from 0.34 to 0.38. Greater variability was found in 1985, with coefficients of variation ranging from 0.42 to 0.44.

Greater variation was observed when the Kc pan values were analyzed on a biweekly basis. Table 5 contains the biweekly pan crop coefficients calculated in 1984 and 1985. Values range from 0.68 to 1.51, and no seasonal trend is evident. Meyer et al. (1985) also observed large variations in crop coefficients based on the evaporation pan method for cool-season turfgrasses.

CONCLUSION

Water conservation on turfgrasses in the Northeast should focus on management practices such as irrigation scheduling or selecting drought-tolerant grasses. The modified Penman equation consistently predicted ET rates for the five grasses included in this study, and would be a reliable and effective tool for scheduling irrigation of turf in southern New England. Our data indicate that a Kc value of 1.0 would be appropriate for irrigation scheduling on all the grasses studied. The pan evaporation method is not as consistent as the modified Penman equation in predicting turf water use in southern New England.

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