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Comparative Turfgrass Evapotranspiration Rates and Associated Plant Morphological Characteristics

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ABSTRACT

Since water costs are projected to increase substantially, and water availability for turfgrass culture will become more limiting, there is a need for a detailed characterization of water use rates among turfgrass species. The evapotranspiration (ET) rates of 11 C-4 warm-season turfgrasses and one C-3 cool-season turfgrass were evaluated in minilysimeters with fritted clay as the rooting medium utilizing the water balance method. Turf plots of 1.5 × 1.5 m were constructed to ensure a natural environment surrounding each lysimeter. Evapotranspiration rates plus six morphological characteristics of each species were measured under nonlimiting soil moisture. Significant differences in ET rates were observed both among and within genera. 'Texas Common' buffalograss [*Buchloe dactyloides* (Nutt.) Engelm], 'Georgia Common' centipedegrass [*Eremochloa ophiuroides* (Munro.) Hack], 'Arizona Common' bermudagrass [*Cynodon dactylon* (L.) Pers.], 'Tifgreen' and 'Tifway' bermudagrasses [*C. dactylon* (L.) Pers. × *C. transvaalensis* Davy], and 'Adalayd' seashore paspalum (*Paspalum vaginatum* Sw.) had low ET rates; while 'Emerald' zoysiagrass (*Zoysia japonica* Steud. × *Z. tenuifolia* Willd. ex Trin.) was characterized as having a medium ET rate. 'Texas Common' St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] and 'Meyer' zoysiagrass (*Z. japonica* Steud.) possessed medium low ET rates. However, a 1-yr study showed that 'Kentucky 31' tall fescue (*Festuca arundinacea* Schreb.) and 'Argentine' bahiagrass (*Paspalum notatum* Flugg.) had medium ET rates, and 'Common' blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] possessed a medium low ET rate. Those grasses with comparatively lower ET rates were generally characterized by (i) a high canopy resistance, including a high shoot density and relatively horizontal leaf orientation; and (ii) a low leaf area, including a slow vertical leaf extension rate and a narrow leaf texture.

Additional Index Words: ***Bouteloua, Buchloe, Cynodon, Eremochloa, Festuca,*** **Leaf orientation, Leaf texture,** ***Paspalum,*** **Shoot density,** ***Stenotaphrum,*** **Vertical leaf extension rate,** ***Zoysia.***

MORE THAN 50% of water used in Texas in 1980 was for irrigation. In 1980, 3.3 billion m^3 of water were used by municipalities and rural communities of Texas (1). This consumption is expected to double by the year 2000. Since water costs are projected to increase substantially, and water availability for turfgrass culture will become more limited, research is needed to delineate the comparative water use rates of turfgrass species.

Interspecies evapotranspiration (ET) differences have been reported among tall fescue, St. Augustinegrass (both the common species and a dwarf cultivar), bermudagrass ('Santa Ana' and 'Suwannee') Emerald zoysiagrass, matrella zoysiagrass [*Zoysia matrella* (L.) Merr.], kikuyugrass (*Pennisetum clandestinum* Hochst. ex. Chiov.), seashore paspalum, centipedegrass, perennial ryegrass (*Lolium perenne* L. 'Pennfine'), and Kentucky bluegrass (*Poa pratensis* L.) (4, 13). The cutting height, N level, or both were varied among species in all three field studies. This confounds the genetic and cultural influences on ET. Biran et al. (4) concluded that cool-season grasses used 45% more water than warm-season grasses, and observed that among warm-season species, the sparse, tall-growing grasses tended to have high ET rates, whereas the dense, low-growing grasses had low ET rates. The ET rates in their study exceeded pan evaporation. Intraspecies differences in ET rates have been reported among St. Augustinegrass, bermudagrass, and zoysiagrass cultivars (4) and among Kentucky bluegrass cultivars (3, 9). There is a need to assess the comparative ET rates of turfgrass species and cultivars under a uniform cultural regime and to determine the relationships of ET rates to specific plant morphological parameters.

Evapotranspiration is a function of plant, soil, and meteorological factors. Literature demonstrates the relationships between ET rates and net radiation, soil moisture content, air temperature, soil temperature, pan evaporation, wind velocity, relative humidity, and the temperature gradient between air and leaf surface (4, 5, 6, 10, 11).

The objectives of this study were (i) to determine the comparative ET rates of 12 turfgrasses under nonlimiting soil moisture conditions, (ii) to assess the relationships between ET rates and specific plant morphological characteristics, and (iii) to determine the relationships between environmental parameters and the ET rates for each species.

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MATERIALS AND METHODS

The 12 turfgrass species or cultivars included in this study were: Arizona Common bermudagrass, Tifway and Tifgreen bermudagrasses, Meyer zoysiagrass, Emerald zoysiagrass, Georgia Common centipedegrass, Texas Common buffalograss, Common blue grama, Kentucky 31 tall fescue, Adalayd seashore paspalum, Argentine bahiagrass, and Texas Common St. Augustinegrass. Blue grama and bahiagrass were dropped from the May 1984 study, and tall fescue was dropped from the September 1984 study due to weedy plot and/or poor growth in the pots. Turf establishment for both plot and pots was achieved during the latter half of the 1981 growing season prior to the year when the studies were initiated and during the summer of 1984. While the other nine grasses were vegetatively propagated, blue grama, tall fescue, and bahiagrass were seeded at rates of 310, 400, and 480 kg ha^{-1}, respectively, on a pure, live-seed basis. One- and three-year-old plants in pots were used for the 1982 and May 1984 studies, respectively, while 3-wk-old plants in pots were used for the September 1984 study. A nonlimiting soil moisture regime was sustained throughout the establishment phase.

The potential evapotranspiration rates of 12 turfgrasses were assessed under comparable cultural practices and environmental conditions. The grasses were mowed at a 3.8-cm cutting height and fertilized at the rate of 12.5 kg N ha^{-1} biweekly. Mowing was accomplished with a properly sharpened rotary mower and hand clippers for plot area and pots, respectively; the clippings were removed. The P and K soil levels were tested by the Soil Testing Laboratory at Texas A&M University, which suggested adding K. The soil moisture level was maintained in the nonlimiting range. No pesticides were applied during the course of the studies.

Experiments were conducted on a site that had been specially constructed as a contiguous plot area. The experimental design was a randomized block design with three replications. Each 1.5- × 1.5-m plot was surrounded by metal barriers to a 10-cm depth to impair the encroachment of adjacent grass species. The root zone was a well-drained sand (USGA specifications) 1.5 m in depth. Subsurface drainage was provided via 10-cm-diam plastic drain lines spaced 3 m apart. Irrigation, via a rotary pop-up sprinkler system, was applied for 30 min daily, which was equivalent to 10 mm water d^{-1}, during the period when all lysimeters were removed to conduct the ET measurements. Fertilization and mowing practices for the general experimental area were the same as those described for the turfs growing in minilysimeters.

Evapotranspiration rates were determined by the water balance method. Black plastic minilysimeters were 21.6 cm in diameter by 20 cm in depth. Each lysimeter was filled with a fritted clay described by Van Bavel et al. (12). This was chosen as the growing medium because of its low bulk density, rapid drainage, and ability to retain a large quantity of plant available water. The sleeves surrounding each minilysimeter were constructed of 0.7-mm (24 gauge) sheet metal as open-end cylinders with dimensions of 22-cm diam by 20-cm depth. One metal sleeve was placed in the center of each 1.5- × 1.5-m turfed plot. Minilysimeters were positioned in these metal sleeves over a well-drained gravel subbase.

Each day at approximately 0900 h, the turfed lysimeters were removed from their metal sleeves, mowed, and watered at a rate of 1 L per minilysimeter. After 90 min, when the pot stopped leaking, the soil-water content reached about 0.47 kg kg^{-1}, which was equivalent to -0.001 MPa (12). Each lysimeter was then weighed on a Mettler P1ON balance, (Mettler Instrument Corp., Heightstown, NJ), which had an accuracy of ± 0.5 g. Each minilysimeter was weighed again the next morning at 0900 h in the same order, and the leaf extension rate was measured. The ET rate was then calculated on a daily basis. The coefficient of variation for this evaporation assessment technique during the 1982 study was 7.3. The study was conducted over a 3-wk period with a total of 12 daily ET rate measurements taken per replicate of each species or cultivar. In 1984 four and 10 daily ET rate measurements were taken per replicate of each species or cultivars in May and September, respectively.

Shoot density, the number of leaves per square meter, leaf orientation, vertical leaf extension rate, and leaf width were measured upon termination of the study, the first three being indicators of canopy resistance aspect and the last two being indicators of leaf area. Leaf width measurements were taken from the midpoint of the third fully expanded leaf from the top. Leaf extension rates were obtained from the daily shoot height differences measured from the top of the pot to the tip of the representative shoots. Leaf orientation was estimated visually based on a 0 to 9 scale, with 9 being entirely vertical and 0 being entirely horizontal. Presence and degree of pubescence on the leaf blade were visually observed.

The 1983 study was initiated; however, due to poor plant growth, it was aborted. In 1982, the study was conducted in August. To avoid duplication with a drought study, the 1984 study was conducted in May and September.

Average daily maximum and minimum air temperatures 1.5 m above the soil surface, average maximum and minimum soil temperatures 0.3 m below the soil surface, and pan evaporation were measured at the TAES class A National Weather Service Station located 20 m from the ET experimental area. Net radiation was measured at the ET experimental area on an hourly basis with a Miniature Net Radiometer installed 1 m above the turfgrass canopy. A CR5 Digital Recorder (Campbell Scientific, Inc., Logan, UT) was used to collect the data.

Comparisons within the ET rates and the plant morphological characteristics for each species or cultivar were made by Duncan's multiple range test at the $P = 0.05$ level. Simple correlations of ET rates to five environmental parameters were determined.

RESULTS AND DISCUSSION

Comparative ET rates from both the 1982 and the 1984 studies are shown in Table 1. The mean ET rate over a 2-yr period ranged from 4.8 to 6.0 mm d^{-1} for nine species. Significant differences in ET rates were

Table 1. Comparative ET rates of 12 turfgrasses grown under nonlimiting soil moisture and uniform cultural conditions.

	ET rates		
Turfgrass species and cultivar	Aug. 1982	May 1984	Sept. 1984
		mm d^{-1}	
Buffalograss, Texas Common	5.3a*	4.6ab	4.4a
Centipedegrass, Georgia Common	5.5abc	4.7ab	4.9bc
Bermudagrass, Arizona Common	5.8bcd	4.2a	4.9bc
Bermudagrass, Tifgreen	5.4ab	4.6ab	5.2c
Bermudagrass, Tifway	5.9de	4.1a	4.9bc
Seashore paspalum, Adalayd	6.2ef	5.1b	4.7ab
Zoysiagrass, Meyer	5.8cde	4.7ab	5.6d
St. Augustinegrass, Texas Common	6.3f	4.8ab	5.6d
Zoysiagrass, Emerald	6.5f	4.9b	6.0e
Bluegrama, Common	5.7bcd	--	--
Bahiagrass, Argentine	6.3f	--	--
Tall fescue, Kentucky 31	7.1g	5.1b	--
CV	7.3	11.8	12.8

* Means with the same letter in a column are not significantly different at the $P = 0.05$ level in Duncan's multiple range test.

Table 2. Shoot densities, number of leaves per unit area, leaf orientation, leaf extension rates, and leaf widths of 12 turfgrasses.

	Canopy resistance components			Leaf area components	
Turf species and cultivar	Shoot density ($\times 10^3$)	No. leaves per area ($\times 10^3$)	Leaf orientation†	Vertical leaf extension rate	Leaf width
	no. m^{-2}			mm d^{-1}	mm
Buffalograss, Texas Common	332e*	1730d	8.7a	2.8abcde	1.7fg
Centipedegrass, Georgia Common	732de	2170d	2.7i	1.3e	3.4c
Bermudagrass, Arizona Common	1800c	2510d	4.7fg	3.2abcd	1.9ef
Bermudagrass, Tifgreen	2612ab	5120b	4.3h	1.5de	0.9hi
Bermudagrass, Tifway	2308b	4560b	5.0gh	1.8cde	0.8hi
Seashore paspalum, Adalyd	1920c	3730c	4.3h	3.9ab	2.6de
Zoysiagrass, Meyer	788d	2360d	7.7bc	2.7abcde	2.9cd
St. Augustinegrass, Texas Common	372de	1650d	6.0ef	2.2bcde	8.0a
Zoysiagrass, Emerald	2932a	7550a	7.7bc	2.2bcde	1.9efg
Blue grama, Common	412de	1770d	8.3ab	4.4a	1.2fgh
Bahiagrass, Argentine	388de	1610d	6.7de	3.5abc	5.0b
Tall fescue, Kentucky 31	612de	1990d	7.3cd	2.7abcde	3.6c
CV	13.8	10.9	8.5	74.2	21.3

* Means with the same letter in a column are not significantly different at the $P = 0.05$ level in Duncan's multiple range test.

† Based on a 0 to 9 scale: 0 = horizontal and 9 = vertical.

observed among different genera and within the same genus such as *Zoysia*. Classification of ET rates followed the table by Beard (2). They are low (<5.5 mm d^{-1}), medium low (5.5–6.0 mm d^{-1}), medium (6.0–7.0 mm d^{-1}), medium high (7.0–7.5 mm d^{-1}), and high (>7.5 mm d^{-1}).

Associated Plant Morphological Characteristics

The ET rate differences among species/cultivars were associated, to varying degrees, with their respective shoot density, the number of leaves per unit area, leaf orientation, leaf width, and vertical leaf extension rate (Table 2). The first three plant parameters contributed to a high canopy resistance to ET, while the latter two parameters affected the total leaf area and resultant amount of evaporative surface. The external canopy resistance to ET has been shown to be much greater than the internal plant resistance (7). A turf canopy with high leaf and shoot densities, a substantial horizontal leaf orientation, or both would cause greater resistance to the normal upward movement of water vapor through the canopy and, at the same time, would decrease turbulent eddy movements with a resultant increase in vapor density within the canopy.

St. Augustinegrass exhibited a medium low ET rate of 5.8 mm d^{-1}. This response was associated with a low canopy resistance in terms of a very low shoot density and an intermediate leaf orientation, plus a high leaf area due to a very wide leaf and a medium vertical leaf extension rate.

Bahiagrass showed a medium ET rate of 6.3 mm d^{-1} when grown under nonlimiting soil moisture. This response was associated with a rapid vertical leaf extension rate and a wide leaf that resulted in a high leaf area, plus a very low shoot density and intermediate leaf orientation, which contributed to a low canopy resistance. However, this value is from the 1982 study, which showed higher values than the May 1984 and the September 1984 studies mainly due to the August measurement. Thus, special consideration should be taken in terms of ranking this species.

Adalayd seashore paspalum showed a low ET rate of 5.4 mm d^{-1}. This rate was associated with a very rapid vertical leaf extension rate but a medium leaf width, horizontal leaf orientation, high shoot density, and the number of leaves per unit area.

Significant differences were found within the zoysiagrasses. Emerald showed a medium ET rate of 6.0 mm d^{-1}, which was the highest ET among the C-4 grasses, while Meyer showed a medium low ET rate of 5.5 mm d^{-1}. The medium ET rate of Emerald may be associated with its vertical leaf orientation and medium vertical leaf extension rate, in spite of a high shoot density and a large number of leaves. Meyer was intermediate in the morphological components that influence the ET rate.

The ET rates of the three bermudagrasses were in the low range. Arizona Common, Tifgreen, and Tifway ranked low in ET rates at 5.1, 5.2, and 5.2 mm d^{-1}, respectively. A slow vertical leaf extension rate and a narrow leaf that resulted in a low leaf area, plus a high shoot density and a rather horizontal leaf orientation, may have contributed to the low ET rates of bermudagrasses.

Centipedegrass showed a low ET rate, which is contradictory to the results of Biran et al. (4). The canopy characteristics of the centipedegrass used in the latter study were not described. The low ET rate of 5.1 mm d^{-1} for centipedegrass found in this study was attributed to very slow vertical leaf extension rate, plus a near-horizontal leaf orientation and prostrate growth habit that contributed to a high canopy resistance to ET.

The native grass, buffalograss, showed low ET rate of 4.8 mm d^{-1}. Pubescence on the leaf blade surface and the low leaf area may have contributed to the very low ET rate of buffalograss. Buffalograss had a very sparse shoot density and very narrow leaf blades, which contributed to the lower exposed leaf surface to the air. There is the possibility that physiological adjustments within the plant may have contributed to the lowest ET rate of buffalograss.

Another native grass, blue grama, had a medium low ET rate of 5.7 mm d^{-1} in the 1982 study. This medium low ET rate was associated with a low leaf area due to a sparse shoot density and narrow leaf width.

Tall fescue, a C-3 cool-season turfgrass, had a higher ET rate than any of the 11 C-4 grasses in both the

1982 and the May 1984 studies. This is consistent with the results of Biran et al. (4). The medium ET rate of 6.1 mm d^{-1} for tall fescue was associated with its fairly erect leaf orientation and low shoot density, which contributed to a low canopy resistance, plus an intermediate vertical leaf extension rate and a medium wide leaf as well as its C-3 photosynthetic pathway.

Influence of Environmental Factors on ET Rates

Highly significant correlations were found between ET rates under nonlimiting soil moisture conditions and the nearby net radiation, pan evaporation, air temperature, and relative humidity measurements for all grasses except buffalograss. Net radiation was the most highly correlated with ET rates for the 12 grasses. The dense pubescence of the buffalograss leaves increased the thickness of the boundary layer on the leaf surfaces and, therefore, might diminish the correlations with both pan evaporation and relative humidity. It should be noted that, except for net radiation, these environmental parameters were monitored at a site approximately 20 m from the ET experimental area. Thus, these correlations should be assessed in terms of predictive parameters. It is evident that the relative prediction effectiveness differs among species, with buffalograss, bahiagrass, and centipedegrass ranking the poorest.

Soil temperature was not correlated with the ET rate for all grasses under nonlimiting soil moisture conditions. While air temperature directly influences the ET rates of plants by affecting the water vapor pressure deficit, the temperature of the soil is known to influence water uptake by plants in terms of the capability of roots to absorb water. In addition, the resistance to water movement through the soil is temperature dependent. In a study by Tew et al. (10), the soil temperatures ranged from 10 to 40°C, which was wide enough to significantly influence ET. Since the soil temperature range, 27.8 to 31°C during this study, was very narrow and favorable for root activity, soil temperature did not affect the ET rate significantly. This concept can be supported by the significant correlation of ET rates to soil temperature when under progressive water stress conditions, as documented in a subsequent study (8). The soil temperature range in this latter case was from 19 to 28°C.

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