Published online March 15, 2018

RESEARCH

Evapotranspiration Rates of Turf Bermudagrasses under Nonlimiting Soil Moisture Conditions in Oklahoma

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ABSTRACT

Due to limited water availability and increasing water costs, it is essential to identify and utilize turfgrasses with reduced water use rates. The objective of this study was to evaluate the evapotranspiration rates of bermudagrass (*Cynodon* spp.) genotypes under nonlimiting soil moisture conditions in the field at Stillwater, OK. Evapotranspiration rates of 10 bermudagrass genotypes were determined using mini-lysimeters with calcined clay as rooting media. Daily evapotranspiration (ET) rates were measured before dawn by weighing the mini-lysimeters from August to September in 2013, 2014, and 2015. A significant genotype × year effect was found. Therefore, data were analyzed separately for each year. Within years, the genotype × date effect was significant only in 2014. In 2013, 'TGS_U3', 'TifTuf', and 'Premier' used more water than OKC 1302, OKC 1163, 'Latitude 36', 'Tifway', and OKC 1131. In 2014, TifTuf, 'Celebration', Tifway, and OKC 1302 used more water than Premier, TGS_U3, 'NorthBridge', OKC 1163, and OKC 1131. In 2015, TifTuf, Celebration, and Latitude 36 used more water than Premier, OKC 1302, OKC 1163, OKC 1131, and NorthBridge. TifTuf ranked consistently in the group of genotypes with the highest ET rates, whereas OKC 1131 ranked consistently in the group of genotypes with lowest ET rates in 2013, 2014, and 2015. The differences in ET rates show the potential for breeding programs to develop bermudagrass cultivars with lower ET rates, which may result in reduced overall ET requirements.

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Abbreviations: ET, evapotranspiration; NTEP, National Turfgrass Evaluation Program; PVC, polyvinyl chloride.

WATER AVAILABILITY for human consumption and irrigation has become limited in recent years. A continuous increase in water demand and in drought stress during the summer months has reduced water availability for nonfood commodities (Hanks, 1983). Urban landscaping, especially turfgrass, is often the first to face watering restrictions due to municipal irrigation rationing and ordinances (Ozan and Alsharif, 2013). Water requirements for turfgrass are based on water use rates, which are typically quantified through measurements of evapotranspiration (ET) rates. During the growing season, ET rates of most turfgrass range from 3 to 8 mm d^{-1} and can be as high as 12 mm d^{-1} (Beard, 1973). The ET rates of warm-season grasses fluctuate over time and have been reported to range from 0.5 mm d^{-1} during winter to 5.0 mm d^{-1} during late spring and early summer in a lysimeter study conducted in Florida (Wherley et al., 2015).

The ET rates of plants are a function of soil moisture, plant type, stage of plant development, and weather (Brown, 2014). Adequate and available soil moisture increases water consumption, which results in increased turfgrass water use rates (Kneebone and Pepper, 1984). Turfgrass water requirements vary among species

Published in Crop Sci. 58:1–7 (2018).
doi: 10.2135/cropsci2017.08.0493

and among cultivars within the same species. Plant morphological and growth characteristics such as shoot and leaf density, leaf extension rates, leaf width, number of leaves per unit area, vertical leaf extension rate, and leaf and shoot orientation also affect ET rates (Ebdon et al., 1998; Ebdon and Petrovic, 1998), often by increasing canopy, stomatal, or cuticular resistance (Beard, 1989). The ET rates of turfgrasses are also affected by environmental factors such as solar radiation, temperature, humidity, and wind speed (Carrow, 1995). Turfgrass irrigation requirements may also increase with increasing maintenance intensity (Duble, 1996). Under low-maintenance conditions, warm-season grasses were found to maintain acceptable turf quality with irrigation at 10 to 50% of evaporation from a Class A pan (Qian and Engelke, 1999), whereas intense management conditions required irrigation at 60 to 80% of evaporation (Carrow, 1995).

Various research trials have been conducted to evaluate turfgrass ET rates under well-watered conditions, where turfgrass was watered to field capacity to prevent visual wilt symptoms during the entire study (Kim and Beard, 1988; Beard et al., 1992; Wherley et al., 2015). The most common methods for estimating actual ET are lysimeter weighing, the Bowen ratio–energy balance, and the Eddy covariance system (Gavilán and Castillo-Llanque, 2009). Lysimeters are the standard instrument for measuring turfgrass ET rates (Qian et al., 1996). Precise measurements of ET can be achieved by measuring moisture change in a confined body of soil (van Bavel, 1961). Evapotranspiration measurements in the field are difficult due to variation in soil physical properties, soil moisture, and vegetation types, but the use of field lysimeters have made ET measurements more easily obtainable (van Bavel, 1961; Rogowski and Jacoby, 1977; Kopec et al., 1988). However, for accurate ET measurement, certain requirements of lysimeter construction and operation must be considered. Grasses grown in lysimeters may have more available water for evaporation during a dry period, and the root system of grasses grown in lysimeters may differ from that grown in the surrounding area (van Bavel, 1961). This can be reduced by making the lysimeter relatively deep (van Bavel, 1961). Calcined or fritted clays have also been routinely used as a rooting media in plant water use and lysimeter experiments (Kopec et al., 2004). Calcined clays have the advantage of providing a uniform rooting media with relatively good ability to hold plant available water. They also have a uniform bulk density that is consistent and reproducible, have excellent drainage, and are light weight, making it easier for researchers to handle and weigh individual lysimeters in the field (van Bavel et al., 1978).

Kim and Beard (1988) conducted research under nonlimiting soil moisture conditions to evaluate the ET rates of one cool-season and 11 warm-season turfgrasses. Turfgrass ET rates were evaluated in black plastic mini-lysimeters with fritted clay as rooting media. The mini-lysimeters were watered to prevent wilting, and it was assumed that ET rates were not limited by soil moisture. Significant differences in ET rates were observed among genera and among species of the same genus. Differences in ET rates were related to morphological characteristics that affected canopy resistance or leaf area.

Wherley et al. (2015) studied ET rates and developed crop coefficient values for four warm-season turfgrasses, including 'Tifway' bermudagrass (*Cynodon* spp.), using lysimeters filled with native soil in Florida. The actual ET rates of Tifway bermudagrass ranged from 0.5 mm d^{-1} in winter months to 5 mm d^{-1} during summer months. The researchers did not report if ET rates among species differed due to morphological characteristics. There was also no clear relationship between bermudagrass clipping dry weight or root dry weight and bermudagrass ET rates.

Selection of drought-resistant and low-water-use species and cultivars can improve water conservation efforts and turf performance under reduced water conditions (Carrow, 1996a, 1996b). A study conducted using commercially available cultivars of cool-season turfgrass demonstrated that grasses having lower ET rates during drought-stress conditions resulted in greener turf (Zhao et al., 1994). Similarly, a lysimeter study of eight bermudagrass genotypes showed that those with lower ET rates remained green for longer periods after a drought treatment (Zhou et al., 2009). It also showed that the genotypes having lower ET rates had more available soil water at later stages of the drought treatment. Generally, bermudagrasses have superior drought resistance as compared to other warm-season turfgrass species (Carrow, 1995; Qian et al., 1997).

A considerable amount of water is used for landscape irrigation; therefore, it is important to identify and select turfgrasses that use less water. Interspecific variations of water use rates among bermudagrass, zoysiagrass (*Zoysia* spp.), seashore paspalum (*Paspalum vaginatum* Sw.), and St. Augustinegrass [*Stenotaphrum secundataun* (Walter) Kuntze] have been evaluated under field conditions (Kim and Beard, 1988; Carrow, 1995; Carrow, 1996b; Kopec et al., 2004; Wherley et al., 2015). However, only a small number of commercially available bermudagrass genotypes have been characterized for water use rates. Therefore, the objective of this study was to evaluate the water use rates of commercial and experimental bermudagrass genotypes under nonlimiting soil moisture conditions in Oklahoma.

MATERIALS AND METHODS

Research Site and Experimental Design

This research was conducted in August and September of 2013, 2014, and 2015 at the Oklahoma State University Turfgrass Research Center in Stillwater, OK. The soil at the research site was an Easpur silty clay loam (a fine-loamy, mixed, thermic Fluventic Haplustoll). The field design was a completely randomized block design. Each cultivar was replicated three times in 2.4-m × 2.4-m plots, which were separated from each other by 0.3-m soil borders. Each plot had a polyvinyl chloride (PVC) sleeve (15.2-cm diam. and 0.5-cm thickness) in the center, which held the lysimeter beneath the soil so that each lysimeter was even with the plot surface. Prior to inserting the PVC sleeves into the field plots, a uniform volume of soil, equal to the volume of the PVC sleeves, was removed carefully so that the surrounding soil was not disturbed.

Mini-Lysimeter Construction

Mini-lysimeters were constructed from PVC pipes 15.2 cm in diameter and 35.6 cm in length with a root zone depth of 30.48 cm, as described by Kopec et al. (2004). The bottom of each mini-lysimeter was constructed using a PVC sheet with a diameter of 15.2 cm. Attached to each PVC sheet was a strainer and drain valve. The 0.635-cm threaded ball valve (Grainger International, 0.635-cm male × female valve) was used for drainage. The strainer washers (2.54-cm diam. and 1.27-cm, high-domed filter screen) were attached to the top of the drain valves. Geotextile porous sheets were also kept at the bottom of the mini-lysimeter to protect the valves from clogging by rooting media. The mini-lysimeters were filled with calcined clay (Turface Pro League) screened to a particle size of 1 to 2 mm in diameter. Calcined clay, also known as fritted clay, is a coarsely milled and kiln-fired clay often used as a granular growth medium. Calcined clay has a relatively low dry bulk density, is noncohesive, drains very rapidly, retains a large quantity of plant available water, is considered to be chemically inert, and can easily be washed off roots (van Bavel et al., 1978). The bulk density of the calcined clay used in this study was 0.65 g cm^{-3}, which is similar to the bulk density of calcined or fritted clays used in previous research studies (van Bavel et al., 1978; Bigelow et al., 2004; Curtis and Claassen, 2008).

Plant Materials and Field Establishment

Ten bermudagrass genotypes were evaluated in this trial. The standard genotypes evaluated were cultivars 'Celebration, 'TGS_U3' (Tulsa Grass and Sod Farm produced U3 sod; sourced from Tulsa, OK), Tifway, 'Premier', 'Latitude 36', 'NorthBridge', and 'TifTuf'. The experimental genotypes evaluated were OKC 1302, OKC 1131, and OKC 1163. Celebration is an economically important common bermudagrass that has improved drought and shade tolerance and a fast recuperation rate. TGS_U3 is a common bermudagrass used in many residential yards and for golf course fairways in Oklahoma. Tifway is the most widely used hybrid bermudagrass on golf course fairways in the United States. Premier is a hybrid bermudagrass with excellent turfgrass quality. Latitude 36 and NorthBridge are hybrid bermudagrass from Oklahoma State University that have shown promising features in the National Turfgrass Evaluation Program (NTEP). Tiftuf is a newly released hybrid bermudagrass that is known for its drought tolerance and excellent turf quality. OKC 1302, OKC 1131, and OKC 1163 are experimental hybrid bermudagrasses from Oklahoma State University that have shown high overall turf quality and field performance in prior testing at Oklahoma State University and in National Bermudagrass Tests conducted by the NTEP. In preparation for transplanting to the field and to the mini-lysimeters, all grasses were clonally propagated in a greenhouse. Three 15.3-cm-diam. circular plugs of each cultivar were collected from well-established mature turf plots. The plugs were washed to remove all the soil, separated individually, and transplanted to a flat tray containing metro-mix professional growing media on 8 Mar. 2013. Grasses were grown in a flat tray in the greenhouse for 8 wk, and 10 uniform stolons were transplanted into mini-lysimeters on 10 May 2013. In total, 30 mini-lysimeters were transplanted, making three replications of each cultivar, which were allowed to establish in the greenhouse for 12 wk before data collection. The greenhouse was maintained at 30/25°C day/night temperature. The grasses in the mini-lysimeters were maintained at a cutting height of 2.5 cm using hand scissors. The mini-lysimeters were fertilized twice a week for a total of 49 kg N ha^{-1} per month with a nutrient solution of 20–8.6–16.6 N–P–K general-purpose fertilizer (J.R. Peters) plus micronutrients.

Before moving the lysimeters to the research site, field plots were established on 24 May 2013 by sprigging with the respective grasses from greenhouse-grown sprigs. Newly established field plots were hand irrigated three times per day for 1 wk using a handheld water hose. Once the grasses were established, an automatic irrigation system was used to supply irrigation at 100% of reference ET calculated using data obtained from the Oklahoma Mesonet weather station located ~400 m from the field plot area. The plots were mowed three times weekly at 2.5 cm using a riding reel mower. The soil borders were maintained by applying glyphosate to bermudagrass stolons that grew into the borders, and these stolons were simultaneously cut from the edges of the plot with cutting discs to avoid translocation. Fertilizer was applied twice monthly at a rate of 24.5 kg N ha^{-1} from April to September of all years. For weed control, preemergence herbicide oxadiazon (Ronstar 2G, Bayer) was applied at 2.2 kg a.i. ha^{-1} in February and September each year. To prevent insect damage to plots, an insecticide (λ-cyhalothrin) was applied at 0.04 kg a.i. ha^{-1} in August 2014.

Mini-lysimeters were moved to the field research site on 10 Aug. 2013. In the field, each mini-lysimeter was placed into the sleeve such that the top of the canopy in the mini-lysimeter was even with the canopy of surrounding turf in each field plot. The final height of the mini-lysimeters was maintained by placing pea gravel at the base of the in-ground PVC sleeve. Field ET data were collected in August and September of 2013, 2014, and 2015. The mini-lysimeters were transferred to the greenhouse from December to April in 2013 and 2014 to avoid winter injury. To control diseases and insects during this period, preventative fungicides and insecticides were applied. To prevent diseases, pyraclostrobin was applied every 4 wk at 0.06 kg a.i. ha^{-1}. To prevent insects, λ-cyhalothrin and bifenthrin were applied every 4 wk at 0.04 and 0.06 kg a.i. ha^{-1}, respectively.

Data Collection

Data were collected before dawn between 0400 and 0700 h for each testing day in August and September of 2013, 2014, and 2015. The early collection time was to reduce differences in water loss through transpiration during weighing events. The mini-lysimeters were weighed on 15 precipitation-free days in 2013, nine precipitation-free days in 2014, and 12 precipitation-free days in 2015. Weather forecasts were regularly monitored before taking data to avoid precipitation throughout data collection. Meteorological data were recorded from the Oklahoma Mesonet weather station for maximum and minimum air temperature at 1.5 m above soil surface, wind speed at 2 m above soil surface, and solar radiation at 1.8 m above soil surface. Evapotranspiration rates were determined by the water balance method (Rogowski and Jacoby, 1977; Johns et al., 1983) at 24 and 48 h after initial measurements were recorded. On the day of data collection, the lysimeters of each genotype were removed from the sleeves, the drain valves of all mini-lysimeters were closed, and the mini-lysimeters were brought to saturation by filling with water. After complete saturation, the ball valves were opened and the mini-lysimeters were allowed to drain for ~30 min to bring them to field capacity. The mini-lysimeters were considered to be at field capacity when drainage had stopped completely. After bringing the mini-lysimeters to field capacity, the ball valves were closed and the outer walls of the mini-lysimeters were wiped completely dry. The mini-lysimeters were then weighed using a balance (Acculab Vicon, Sartorius Group), and the weight was recorded. The balance had the precision to the nearest 1.0 g, which would provide the ET measurement precision of 0.05 mm d^{-1}. After measuring the weight, the mini-lysimeters were placed back into the sleeves in each plot. The following morning, the mini-lysimeters were pulled out from the sleeves, their outer walls were wiped completely dry, and they were weighed using a balance. After measuring the weight, the mini-lysimeters were reinserted into the respective sleeves in each plot. The difference in the two measurements was used to calculate the 24-h ET rate. On the third day, the mini-lysimeters were cleaned, dried, and weighed again. The grass in the mini-lysimeters was then hand trimmed with scissors to the height of 2.5 cm. After trimming, the mini-lysimeters were watered to field capacity. Once at field capacity, the mini-lysimeters were reinserted into the respective sleeves in each plot, and regular maintenance was resumed until the next data collection event. Turfgrass quality ratings were collected at the beginning and end of each data collection event period according to the NTEP turf quality rating (Morris and Shearman, 2000).

Statistical Analysis

The experimental design was a randomized complete block with 10 genotypes and three replications of each entry. Analysis was conducted on the data using SAS 9.3 (SAS Institute, 2011) software. Analysis of variance was performed using "PROC GLM." There was a significant genotype × year interaction. Therefore, data were analyzed separately by year. In 2014, there was a significant genotype × date interaction; therefore, 2014 data were analyzed by date. When genotype means were separated, Fisher's protected LSD was applied to test at the $P = 0.05$ significance level.

RESULTS AND DISCUSSION

This 3-yr field study was conducted in Oklahoma during August and September of 2013, 2014, and 2015. During the entire study period, turf quality of grasses in the field and lysimeter were maintained at or above minimum acceptable quality levels, and there were no differences in turf quality within bermudagrass genotypes (data not shown). Average daily environmental parameters taken during the field ET study in 2013, 2014, and 2015 indicated differences in air temperature, wind speed, solar radiation, pan evaporation, and reference ET over time (Tables 1 and 2). Significant differences in ET rates were observed among bermudagrass genotypes. Significant genotype and date effects were found within each year. The genotype × date effect was not significant in 2013 and 2015 but was significant in 2014 (Table 3). Therefore, in 2014, ET rates for each day were analyzed and presented separately (Table 4). Evapotranspiration rates fluctuate among genotypes and within genotypes over time. The fluctuation in reference ET and actual ET over time was reported by Wherley et al. (2015). Higher ET rates in our study were observed in 2014 relative to 2013 and 2015. The higher ET rates in 2014 appear to be driven by solar radiation. The fluctuation in ET rates over time due to solar radiation has been reported by Wherley et al. (2015). Since this study was conducted in Oklahoma during months with high evaporative demand and under nonlimiting water conditions, caution should be taken while interpreting these results. The ET rates of these bermudagrasses may differ in other climates and are likely to differ throughout the growing season (Wherley et al., 2015).

Average ET rates during August and September in 2013 and 2015 ranged from 4.14 to 4.74 and 3.60 to 5.15 mm d^{-1}, respectively (Table 3). Similarly, the average ET rates in August and September of 2014 ranged from 3.09 to 6.44 mm d^{-1} (Table 4). These ET rates are similar to ET rates reported in Beard (1989), where warm-season turfgrass ET rates ranged from 4.5 to 8.5 mm d^{-1}, and in Wherley et al. (2015), where bermudagrass rates ranged from 0.5 to 5.0 mm d^{-1}. The significant genotype × year interaction was likely due to differences in environmental conditions (Tables 1 and 2). In other studies, the ET rates were closely associated with net radiation, wind speed, pan evaporation, air temperature, and relative humidity (Kim and Beard, 1988; Beard et al., 1992). The overall difference between the highest and lowest ET groups was 0.89 mm d^{-1} (Table 3), which is similar to the 1.0-mm d^{-1} overall ET range of 24 well-watered bermudagrass genotypes reported by Beard et al. (1992). However, caution should be exercised in comparing the overall means because these studies were not conducted under the same environmental conditions, and the current experiment showed a genotype × year interaction. In 2013, genotypes OKC 1131, Tifway, and Latitude 36 were the genotypes in the lowest water use group and had statistically equivalent ET rates of 4.14, 4.18, and 4.29 mm d^{-1}, respectively (Table 3).

In 2014, ET rates were evaluated for six different days starting on 3 August and ending on 26 September (Table 4). In four out of six periods, ET rates were significantly

Table 1. Average daily environmental parameters taken during the field evapotranspiration (ET) study in 2013 and 2015.

	Air temperature†				Wind speed‡		Solar radiation§		Pan evaporation		Reference ET	
	Max.		Min.									
Year¶	Mean#	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	°C				$m\ s^{-1}$		$MJ\ m^{-2}$		$mm\ d^{-1}$			
2013	33.6	0.4	17.8	1.2	2.2	0.3	22.4	0.8	6.4	0.4	5.2	0.4
2015	34.8	1.0	20.1	1.0	2.7	0.1	21.7	1.3	7.0	0.4	5.5	0.3

† Maximum and minimum air temperature measured at 1.5 m above the soil surface.

‡ Wind speed measured at 2 m above soil surface.

§ Solar radiation measured at 1.8 m above the soil surface.

¶ Evapotranspiration rates were collected on 10 dates and eight dates during August and September of 2013 and 2015, respectively.

Means are the average of 4 d in August and 6 d in September measured from the Stillwater Mesonet weather station located ~400 m from the field plot area.

Table 2. Average daily environmental parameters during the field evapotranspiration study in 2014.

	Air temperature†					
Date	Max.	Min.	Wind speed‡	Solar radiation§	Pan evaporation	Reference ET
	°C		$m\ s^{-1}$	$MJ\ m^{-2}$	$mm\ d^{-1}$	
3 Aug.	31.7¶	17.2	1.0	27.8	6.3	5.3
4 Aug.	32.8	18.9	1.7	27.3	7.1	5.6
13 Aug.	31.1	16.1	1.9	26.9	6.8	5.6
14 Aug.	32.8	18.3	2.9	24.0	7.6	5.8
25 Sept.	30.0	13.9	1.9	19.7	4.8	3.8
26 Sept.	28.8	14.4	2.0	20.5	4.8	3.8

† Maximum and minimum air temperature measured at 1.5 m above the soil surface.

‡ Wind speed measured at 2 m above soil surface.

§ Solar radiation measured at 1.8 m above the soil surface.

¶ Environmental parameters were measured from the Stillwater Mesonet weather station located ~400 m from the field plot area.

different among bermudagrass genotypes. TifTuf consistently ranked in the group of genotypes with the highest ET rates, whereas OKC 1131 ranked consistently in the group of genotypes with the lowest ET rates on all four of these ET measurement days. OKC 1163 and NorthBridge ranked consistently in the group of genotypes with the lowest ET rates for three significant ET measurement days (Table 4). In 2015, OKC 1131, NorthBridge, and OKC 1163 were the genotypes with the lowest water use, with ET rates of 3.60, 3.78, and 3.81 mm d^{-1}, respectively (Table 3). In the same year, TifTuf had a significantly higher ET rate than any other genotype, with a mean of 5.15 mm d^{-1} (Table 3). Celebration, Latitude 36, TGS_U3, and Tifway were not significantly different with ET rates of 4.75, 4.69, 4.59, and 4.57 mm d^{-1}, respectively (Table 3). The ET rates of TGS_U3 and Tifway (Table 3) were similar to ET rates in other studies. Mean ET rates of U3 have been reported to range from 4.1 to 6.5 mm d^{-1} (Beard et al., 1992). Mean ET rates of Tifway have been reported to range from 4.1 to 6.1 mm d^{-1} (Beard et al., 1992) and from 4.1 to 5.9 mm d^{-1} (Kim and Beard, 1988). Similar results were observed in the 2-yr field study conducted by Henry (2007), who reported mean ET rates of Tifway ranging from 2.01 to 7.41 mm d^{-1} in 2006 and from 3.67 to 7.11 mm d^{-1} in 2007.

Variation of ET rates among bermudagrass cultivars in this study (Table 3 and 4) may be associated with grass morphological characteristics. Grasses with lower ET rates

Table 3. Evapotranspiration (ET) rates of 10 bermudagrass genotypes under nonlimiting soil moisture conditions during August and September of 2013, 2014, and 2015.

	ET rate†			
Genotype	2013	2014	2015	Overall
	$mm\ d^{-1}$			
TifTuf	4.69ab‡	5.11ab	5.15a	4.95a
Celebration	4.55bc	5.14a	4.75b	4.77ab
OKC 1302	4.49c	5.19a	4.24d	4.58bc
Premier	4.69ab	4.80c	4.41cd	4.63b
TGS_U3	4.74a	4.75c	4.59bc	4.69ab
Tifway	4.18d	5.09ab	4.57bc	4.54bcd
Latitude 36	4.29d	4.94bc	4.69b	4.59bc
NorthBridge	4.59abc	4.45d	3.78e	4.29cde
OKC 1163	4.47c	4.48d	3.81e	4.26de
OKC 1131	4.14d	4.51d	3.60e	4.06e
CV (%)	7.19	6.19	10.34	21.0
Genotype	*	***	***	***
Date	***	***	***	–
Genotype × date	NS§	*	NS	–
Year	–	–	–	***
Genotype × year	–	–	–	**

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† ET rates were collected on 10, 6, and 8 dates during August and September of 2013, 2014, and 2015, respectively.

‡ Means followed by the same letter within each column are not significantly different at $P = 0.05$.

§ NS, not significant at $P = 0.05$.

Table 4. Mean daily evapotranspiration (ET) rate of 10 bermudagrass genotypes under nonlimiting soil moisture conditions in 2014.

Genotypes	ET rate†					
	3 Aug.	4 Aug.	13 Aug.	14 Aug.	25 Sept.	26 Sept.
	mm d^{-1}					
TifTuf	5.73abc‡	6.28ab	5.68a	5.79ab	3.47a	3.74a
Celebration	6.08a	6.44a	5.80a	5.61abc	3.41a	3.50abc
OKC 1302	5.85ab	6.39a	5.76a	5.93a	3.49a	3.69a
Premier	5.74abc	5.87abc	5.49a	5.28bcd	3.26a	3.20bc
TGS_U3	5.45bcd	5.67bcd	5.81a	5.19dc	3.20a	3.23bc
Tifway	5.70abc	5.96abc	5.79a	5.53abc	3.86a	3.74a
Latitude 36	5.59abc	5.91abc	5.56a	5.67abc	3.38a	3.55ab
NorthBridge	4.90d	5.13d	5.11a	4.92de	3.27a	3.36abc
OKC 1163	5.11dc	5.00d	5.76a	4.55e	3.09a	3.39abc
OKC 1131	5.39bcd	5.29cd	5.11a	4.83de	3.32a	3.10 c
Significance level	*	**	NS§	**	NS	*

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

† Water use in mm d^{-1}. Values are the means of three replications.

‡ Means followed by the same letters within each column are not significantly different at $P = 0.05$.

§ NS, not significant at $P = 0.05$.

are often reported to have characteristics such as high canopy resistance, high shoot density, horizontal leaf orientation, reduced leaf area, narrow leaf texture, and slow vertical leaf extension (Kim and Beard, 1988; Ebdon et al., 1998; Ebdon and Petrovic, 1998). 'Arizona common', 'Tifgreen', and Tifway bermudagrass showed ET rates of 5.1, 5.2, and 5.3 mm d^{-1}, respectively (Kim and Beard, 1988), with reported differences in ET rates associated with differences in leaf texture, shoot density, and leaf orientation. In the same study, 'Texas Common' buffalograss [*Bouteloua dactyloides* (Nutt.) J.T. Columbus] exhibited a significantly lower ET rate of 4.8 mm d^{-1}, which was attributed to pubescence on the leaf blade surface and low leaf area (Kim and Beard, 1988). Although bermudagrass morphological characteristics were not evaluated in this study, OKC 1131 has been reported to possess a relatively high shoot density and high number of leaves per unit area, which could contribute to increased canopy resistance and reduced ET rates. It also has been reported that OKC 1131 has a relatively low vertical leaf extension rate compared with other bermudagrasses, which could contribute to a reduced leaf area and reduced ET (Segars, 2017).

Consistent with our results, Yurisic (2016) also found that TifTuf had a higher water use rate than other bermudagrasses. In their study, TifTuf used 21% more water over a 28-d drought period than Latitude 36 and Tifway. However, although TifTuf used more water, it was able to maintain an acceptable turf quality for a significantly longer time than Latitude 36 and Tifway. Yurisic (2016) also reported that TifTuf produced 41% of its root biomass from 15 to 45 cm, whereas Latitude 36 and Tifway, respectively, produce 22 and 26% of their root biomass at the 15- to 45-cm depth, suggesting that TifTuf was able to use water from deeper within the soil profile due to its rooting characteristics. Although TifTuf was found to have a relatively high ET rate in this study, it is reported to have excellent overall drought resistance, which may be at least partially due to its ability to avoid drought through its rooting characteristics.

In this study, we observed variation in water use rates among 10 bermudagrass genotypes. Although we cannot know the exact mechanisms contributing to these observed differences, variation in ET rates may be associated with morphological characteristics of each genotype, which could be measured in future studies. In this study, the genotypes with higher ET rates used 14 to 43% more water than the genotypes with a lower ET rate in 2013 and 2015 (Table 3). Similarly, the genotypes with higher ET rates had 20 to 30% higher daily ET rates than genotypes having lower ET rates in 2014 (Table 4). These findings suggest that turf managers could potentially save up to 30% of their irrigation water by adopting bermudagrass cultivars with reduced ET rates. When comparing the low- vs. high-water-use genotypes, it should be noted that high-water-use genotypes may not be as susceptible to drought injury in the field due to the presence of drought avoidance characteristics such as deep rooting. Since differences in water use rates among bermudagrass genotypes were observed, selecting and breeding additional bermudagrass cultivars for reduced water requirements appears feasible.

Conflict of Interest

The authors declare that there is no conflict of interest.

Acknowledgments

We greatly appreciate financial support from Sod Solutions and the US Golf Association. We thank Dr. David Kopec for his technical support during construction of the lysimeters, as well as Dr. Kemin Su, Rachana Poudel, Mingying Xiang, Kyungjoon Koh, and Chrissie Segars for their contributions during the course of this research.

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