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Consumptive water use and crop coefficients for warm-season turfgrass species in the Southeastern United States

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ABSTRACT

Increased urban demand for landscape irrigation, as well as interest in promoting water-use efficient species by municipalities, water purveyors, and homeowners associations emphasize the need for comparative data on consumptive water use by warm-season lawn grasses. The objective of this study was to quantify actual evapotranspiration (ET_a) and to develop crop coefficients (K_c) for four warm-season turfgrass species, namely 'Tifway' bermudagrass (*Cynodon dactylon* (L.) Pers. *x Cynodon transvaalensis* Burtt-Davy), 'Empire' zoysiagrass (*Zoysia japonica* Steud.), 'Floratam' St. Augustinegrass [*Stenotaphrum secundatum* (Walter) Kuntze], and 'Argentine' bahiagrass (*Paspalum notatum* Flugge). Crop coefficients were derived by dividing ET_a (measured directly from lysimeter weight change over 24 to 72-h periods) by reference evapotranspiration (ET_o) calculated from the ASCE–EWRI Standardized Method using onsite weather station data. Data were collected over three seasons from non-stressed, well-watered turf. For 17 of the 30 measurement periods, K_c did not differ among the 4 species, and on 24 of 30 periods zoysiagrass, bermudagrass, and St. Augustinegrass K_c did not differ from one another. A trend toward elevated K_c was observed in bahiagrass in years 2 and 3, particularly during early spring measurement periods. K_c values for all species fluctuated across seasons and years, peaking to ~0.8 during active growth periods when vapor pressure deficit and solar radiation were greatest, and declining to ~0.3 in late fall and winter. Root growth differences among the species appeared to have a stronger relationship to ET rates than did shoot growth rate. Results demonstrated that the commonly recommended warm-season turf coefficient of 0.6, while approximating overall average annual ET_a, under-predicted ET_a during active growth periods and over-predicted ET_a during late fall and winter periods, when turf was slowly growing or quiescent. The results indicate seasonal refinement of K_c values may be needed to more effectively meet consumptive water use requirements of warm-season turfgrasses.

1. Introduction

Urbanization and drought have resulted in greater regulation of municipal water supplies, especially for irrigating landscapes. Turfgrasses are a dominant plant type in landscapes and are estimated to account for 163,800 km^2 of area in the U.S., more than three times as much as any other irrigated crops (Milesi et al., 2005). In Florida, as well as many other areas of the southern and western U.S., landscape irrigation accounts for nearly two-thirds of summertime water use and more than half of total annual residential water use (Mayer et al., 1999; Gerston et al., 2002; Haley et al., 2007). Irrigation conservation efforts by water purveyors and municipalities commonly promote lawn irrigation best management practices that accommodate plant demand while minimizing water losses through over-irrigation. Increasingly, drought-tolerant or water-efficient plant lists are also developed by municipalities or home owners associations, which discourage or restrict planting of perceived 'water-wasting' plant material (Anonymous, 2002, 2004, 2010). Although well-intentioned, these are often developed in the absence of scientific information to support such recommendations.

A central component of irrigation management has become the use of weather-based reference evapotranspiration (ET_o) estimates adjusted based on appropriate crop coefficients (K_c). As such,

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development of appropriate K_c values for various species is a critical basis for effective water budgeting. Accurate K_c determination is also fundamental to prescribing tolerable levels of deficit irrigation as it relates to a given species or cultivar for periods of water conservation (Miller and McCarty, 2001; Wherley, 2011; Wherley et al., 2014). Because evapotranspiration (ET) and K_c values can vary among geographic locations and species (Green et al., 1990; Kim and Beard, 1988; Allen et al., 2005), development and use of regional and species-specific K_c data are fundamental to effective water management.

Due to the fact that turfgrass water conservation has traditionally been more of a concern in arid, low rainfall regions, previous irrigation research of this type has been conducted in the southwest or mountain west U.S. (Devitt et al., 1992; Kim and Beard, 1988; Atkins et al., 1991; Green et al., 1991; Kneebone and Pepper, 1982, 1984; Feldhake et al., 1983). Published K_c data for warm-season lawn turfgrasses grown in the southeastern U.S. have been limited. The primary warm-season turfgrasses grown in this hot humid climatic region of the southeast include bermudagrass, zoysiagrass, bahiagrass, and St. Augustinegrass (McCarty, 2011). One study reported ET rates for multiple warm-season grasses in Griffin, GA (Carrow, 1995), however, because the data were developed under intermittent drought stress-conditions (grasses reportedly experienced periodic dry-down events during measurement periods), caution should be used when attempting to apply these in terms of estimating K_c. In another study, Stewart et al. (1969) reported ET rates for Tifway bermudagrass (*Cynodon dactylon* (L.) Pers. *x Cynodon transvaalensis* Burtt-Davy) over multiple seasons in Ft. Lauderdale, FL; however, these too, were evaluated under intermittent drought stress conditions. According to Allen et al. (1998), it is essential that studies aimed at developing K_c be evaluated under well-watered, non-stressed conditions.

In one of the few studies in the southeastern U.S. to determine K_c for warm-season turf under well-watered conditions, Jia et al. (2009) estimated bahiagrass K_c based on eddy covariance measurements in Citra, FL. Based on their findings, the authors suggested K_c values of 0.35 for Jan–Feb, 0.55 for Mar, 0.80 for Apr, 0.90 for May, 0.75 for Jun, 0.70 for Jul–Aug, 0.75 for Sep, 0.70 for Oct, 0.60 for Nov and 0.45 for Dec. These results demonstrated that K_c for bahiagrass fluctuates throughout the year, and during peak growth periods is considerably greater than the commonly recommended warm-season turfgrass K_c of 0.6 to 0.65 (Meyer and Gibeault, 1987; Gibeault et al., 1989; McCarty, 2011). Depending on the soil type and climate, supplemental irrigation may be necessary for maintaining warm-season turfgrass appearance and function during spring, summer, and fall months in many parts of the southern U.S. Despite this, a single warm-season turfgrass K_c is often recommended for ET_o-based irrigation, regardless of the season. There is currently a need for K_c data from studies conducted across seasons involving multiple warm-season turfgrass species. Results from such studies would be useful to regional water purveyors for irrigation planning and permitting, as well as outreach efforts aimed at educating homeowners and irrigators on appropriate seasonal water requirements for turfgrass species in the landscape.

The objective of this 3-yr field study was to utilize weighing lysimetry to measure ET and develop K_c for four commonly used warm-season turfgrass species, namely 'Tifway' bermudagrass (*C. dactylon* (L.) Pers. *x C. transvaalensis* Burtt-Davy), 'Empire' zoysiagrass (*Zoysia japonica* Steud.), 'Floratam' St. Augustinegrass (*Stenotaphrum secundatum* (Walter) Kuntze), and 'Argentine' bahiagrass (*Paspalum notatum* Flugge). Turfgrass quality, shoot growth, and root growth were also evaluated in each species in order to better understand their potential relationship with and possible use as an indicator for ET.

2. Materials and methods

2.1. Field study site

This experiment was conducted from March 2008 through August 2010 at the University of Florida G.C. Horn Turfgrass Field Laboratory, Citra, FL. Established 1-yr old turfgrass field plots (6 m × 6 m) were arranged in a Latin square design with eight replicates and included Tifway bermudagrass, 'Empire' zoysiagrass, 'Floratam' St. Augustinegrass, and 'Argentine' bahiagrass. Soil at the site was a loamy, siliceous, hyperthermic Grossarenic Paleudult Arredondo fine sand. Soil tests for the 0–15 cm depth indicated the soil consisted of 1.1 g kg^{-1} OM and 6.4 pH.

2.2. Lysimeter Installation and Establishment

Lysimeters (25 cm diameter × 33 cm deep) constructed from PVC pipe and round foam board bottoms, were inserted into the center of field plots into in-ground plastic sleeves, constructed from the walls of plastic 18.9 L buckets. The sleeves matched the lysimeter diameter so there was only a 6-mm air gap between the lysimeter and sleeve. Four 17.5-mm holes were drilled into the bottom of each lysimeter to facilitate drainage. Geotextile fabric was used to line the bottoms of lysimeters to prevent loss of sand. A layer of rock (8 to16 mm diameter) approximately 5 cm thick was placed below lysimeters to allow for drainage of excess water from the lysimeters and to allow easy adjustment of lysimeter depth so that the top of the lysimeter and surrounding soil surface were level. A more detailed methodology and description of the lysimeter and sleeve construction/installation has been previously published (Wherley et al., 2009).

Prior to each season (February), lysimeters were filled with the previously described native soil from within the plot area, thoroughly tamped, and sodded, using a 5-cm deep section of sod removed from plots. The newly sodded lysimeters were then placed in the ground and maintained under frequent (2 times daily) irrigation to promote root establishment into lysimeters.

2.3. Cultural management of plots

Turfgrass field plots were maintained under well-watered, non-stressed conditions throughout the study. Plots were irrigated every other day from April through October, and twice weekly from November through March at a level of 100% of historical monthly reference evapotranspiration (ET_o) for the site, based on data from an on-site weather station. Appropriate adjustments were made to irrigation run times to account for rainfall events received during the study.

Plots and intact lysimeters were fertilized three times annually, in April, June, and August, at a rate of 49 kg N ha^{-1} per application. An 18–3–18 ($N:P_2O_5:K_2O$) sulfur coated urea-based fertilizer (John Deere Landscapes, Alpharetta, GA) containing other macro and micronutrients was used. Mowing was performed once weekly from March through November using a rotary mower with clippings returned to plots. Cutting heights were selected to approximate recommended lawn mowing heights for each species (Trenholm et al., 2011b). As such, zoysiagrass and bermudagrass plots were mowed to a 5.1-cm mowing height, while St. Augustinegrass and bahiagrass plots were mowed at an 8.8-cm mowing height. From December through February, shoot growth essentially ceased in plots, but plots did not go fully dormant, as some green shoots were generally noticeable deep within the turf canopy during the winter months. Oxadiazon [5-(*t*-butyl)-3-(2,4-dichloro-5-isopropoxyphenyl)-1,3,4-oxadiazol-2-one] was also applied in February of each season at a rate of 2.5 kg ai ha^{-1} for pre-emergence