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Turfgrass Growth, Quality, and Reflective Heat Load in Response to Deficit Irrigation Practices

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1. Introduction

Turfgrass irrigation practices have come under intense scrutiny in recent years due to concerns over increasing population growth and diminishing water availability. Municipal water restrictions have become commonplace and more recently, the U.S. Environmental Protection Agency has developed guidelines that would restrict irrigation and/or amount of turf within the landscape (Watersense Single Family New Home Specification, 2009). Thus, turfgrass managers are increasingly faced with the challenge of maintaining acceptable turfgrass quality using less water. Understanding the minimal irrigation requirements and extent of water stress that a particular turfgrass species can tolerate while exhibiting acceptable quality is therefore highly valuable information for turfgrass managers and homeowners.

Deficit irrigation is the practice of intentionally under-irrigating of a plant to below its maximum water demand. This practice has been long used in crop production, where it often culminates in overall reductions in growth, development, and yield. Turfgrass systems are perhaps uniquely adapted for deficit irrigation because reductions in shoot growth are perceived to be beneficial, as long as visual and functional quality are not significantly sacrificed. Deficit irrigation has been practiced across a number of species, although the particular level of irrigation needed to maintain acceptable quality appears to vary among species. Using minilysimeters in the field, DaCosta & Huang (2006) determined that bentgrass species required ≥60% ET_a for maintaining acceptable summer quality, but that irrigating at only 40% ET_a was sufficient for maintaining acceptable quality during fall months. Qian and Engelke (1999) found that minimal irrigation requirements for grasses grown along a linear gradient of irrigation ranged from 26% to 68% of Class A pan evaporation (Ep) in a study of five turfgrass species along a linear gradient of irrigation. Feldhake et al. (1984) studied deficit irrigation of three turfgrass species grown in lysimeters and determined that irrigation deficits up to ~27% only decreased growth, but greater deficits resulted in significant loss of quality for Kentucky bluegrass and tall fescue.

Zoysiagrass is a warm-season (C_4) turfgrass native to Southeast Asia, but has become an increasingly popular turfgrass for use on lawns and golf courses throughout the southern half of the United States and many other tropical, subtropical, and temperate regions of the world (Turgeon, 2002). Whereas some turfgrass species are capable of avoiding drought through production of a deep root system, physiological studies indicate that zoysiagrass tolerates drought largely through osmotic adjustment (Qian & Fry, 1997). Very little information is available regarding the minimal irrigation requirements or response of this species to deficit irrigation practices. Therefore, the objective of this study was to determine the response of 'Empire' zoysiagrass to four levels of deficit irrigation and to identify the maximally acceptable irrigation deficit at which acceptable turf quality could be maintained in this species.

2. Materials and methods

This study was carried out from August 27 through October 15, 2008 in a greenhouse at the University of Florida campus in Gainesville, FL. 'Empire' zoysiagrass (*Zoysia japonica* Steud.) was grown in pots constructed from 10 cm diameter, 20 cm tall PVC pipes fitted with a flat end cap. A small hole was drilled into the center of each end cap for drainage. The top, open end of the pipes was fitted with a toilet flange for attaching a photosynthesis chambers. Four weeks prior to deficit irrigation studies, zoysiagrass sod pieces (2.5 cm depth) were removed from established, sand-based research plots at the University of Florida G.C. Horn Memorial Turfgrass Research Field Laboratory, Citra, FL, using a 10-cm diameter golf cup cutter. The sod was washed free of soil and established atop medium-coarse textured sand in PVC pots. A complete slow-release fertilizer (24-5-11, Turfgro Professional, Sanford, FL) was applied and grasses were grown in the greenhouse for four weeks to fully root in the soil prior to deficit irrigation experiments. Greenhouse temperatures during the study period were controlled at 32/22 ºC (day/night). During this time, grasses were clipped weekly at a height of 6.4 cm. Visual observations confirmed that grass roots had reached container bottoms at the start of the experiment. A full cover of turf was also present on all pots at the start of the experiment, so that water loss was primarily a function of transpiration.

The study was initiated by fully saturating all pots. Following 24- hour period, when drainage had ceased, holes in pot bottoms were plugged to prevent drainage for the duration of the six-week study. At this time, four pots were randomly selected to be fully watered controls; and the initial, well-watered weights of these pots were measured. These pots were kept fully watered throughout the study by adding water daily in an amount equivalent to 100% of ET_a, measured gravimetrically. In order to more rapidly attain the desired water stress levels within the irrigation deficit treatments, drought-stress treatments were allowed to dry down the soil as a result of transpirational water loss, as described by Sinclair and Ludlow, 1986. Four plants were assigned to each of four deficit irrigation treatments (80%, 60%, 40%, and 20% of ET_a), which were initiated by allowing soil water content to decrease below that of fully watered controls prior to the beginning of the experiment. For example, in the 80% ET_a treatment, plants were allowed to decrease soil water content until the daily transpiration was measured to be 80% of that for well-watered plants. Upon reaching 80% relative transpiration (RT) rate, this stress level was permanently maintained by replenishing the pots daily with 80% of ET_a. The number of days of soil dry down required to reach targeted stress levels varied from 2 days for 0.8 RT (80% ET_a) to 6 days for the 0.2 RT (20% ET_a) stress treatment. As each of the stress treatments were reached, irrigation was returned to pots daily at 100% (controls), 80%, 60%, 40%, or 20% of ET_a. ET rates within the water stress treatments were also measured each afternoon to determine water loss, and corresponded highly to the prescribed irrigation amounts added to the respective treatments (data not shown). As such, ET of deficit treatments maintained a steady state proportional to fully irrigated controls.

Over the course of the six weeks, data were collected including daily ET rates, turfgrass visual quality, clipping dry weights, degree of leaf wilt and firing, photosynthetic rates, and reflective heat load in response to deficit irrigation. Turfgrass visual quality was visually estimated on a 1-9 scale, with 6 representing minimally acceptable turf (Morris & Shearman, 2006). For measuring clipping dry weights, grasses were clipped to 6.4 cm weekly, with clippings oven dried at 65 C for 72 hrs. Percent leaf wilt and firing were determined weekly by visually estimating the percentage of leaves within the 10 cm diameter plug that were either wilted of firing during the afternoon on a clear day. A portable chamber system modified from that described by Pickering et al., 1993, was used to measure canopy photosynthetic rates within the treatments at the conclusion of the study. This involved a portable photosynthesis system (LI-6200, LI-Cor Inc., Lincoln, NE) with an open leaf chamber mounted inside the translucent canopy chamber (figure 9). Chambers caused a 20% reduction in incoming photosynthetic active radiation (PAR). Three readings were recorded for each pot on a cloudless day during the afternoon hours, during which PAR levels within chambers always exceeded 1200 µmol m^{-2} s^{-1}. Temperatures inside chambers during the measurement period averaged 37.7 +/- 0.2 C. Canopy net photosynthetic rate (Pn) was expressed as CO_2 uptake per unit turf canopy area (m^{-2}). Reflective heat load from within the treatments was determined with a handheld Crop Trak Mini IR thermometer (Spectrum Technology, Plainfield IL) by measuring leaf canopy temperatures during the afternoon on a clear day.

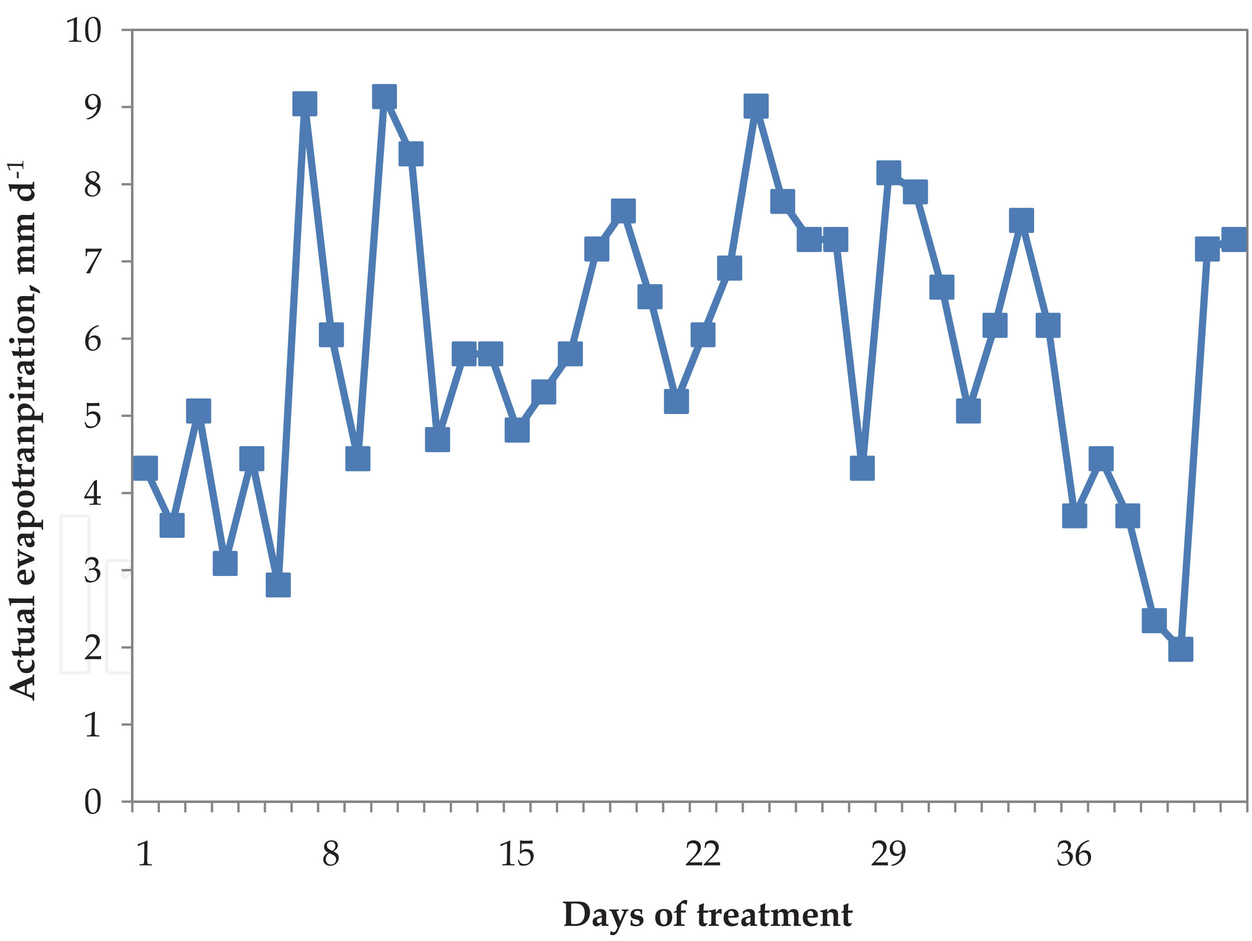

Fig. 1. Mean evapotranspiration (ET_a) rates for 100% ET control plants over the six week study. Amounts are equivalent to the daily irrigation supplied to 100% ET control plants, with deficit ET treatments receiving a fraction (80, 60, 40, or 20%) of this amount

3. Results and discussion

The objective of this study was to determine the response of 'Empire' zoysiagrass to four levels of deficit irrigation, provided daily. Actual evapotranspiration (ETa) and (equivalent to irrigation requirements) for control plants over the 42-day study ranged from 2 to 9 mm d^{-1}, with total irrigation volume applied of 246 mm (Figure 1). Deficit irrigated treatments received a total of 197 mm (80% ETa), 157 mm (60% ETa), 126 mm (40% ETa), and 101 mm (20% ETa).

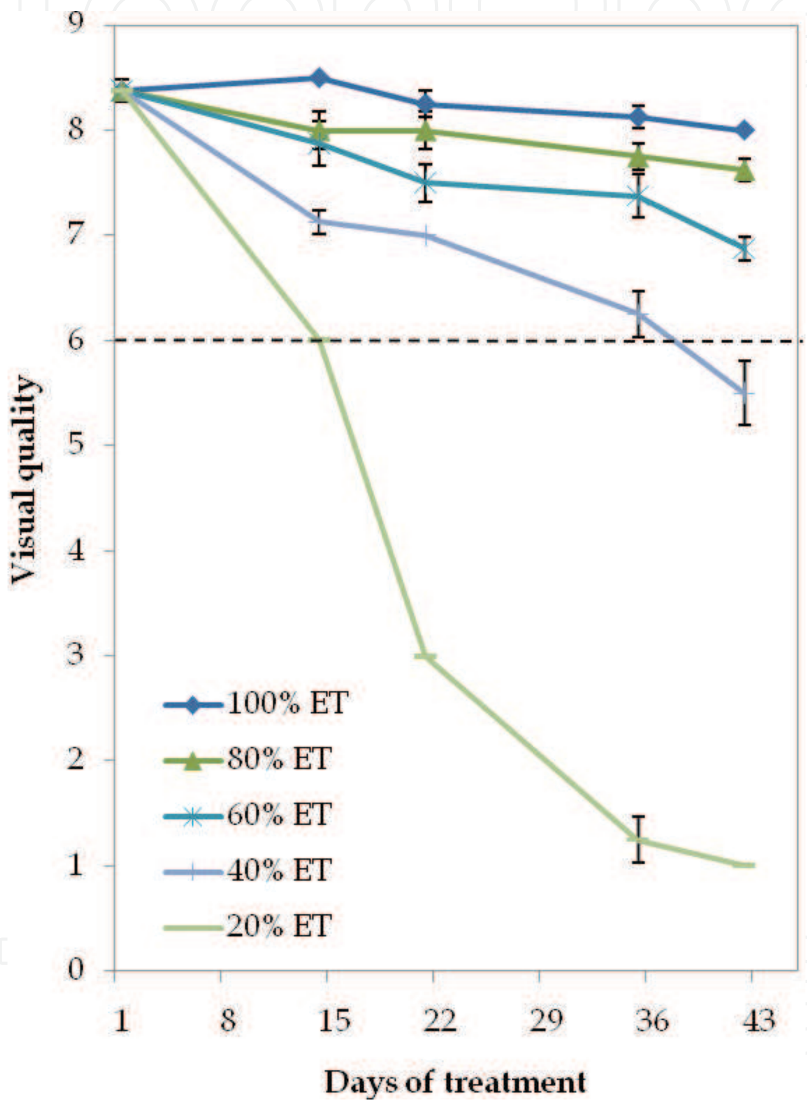

Fig. 2. Visual quality of turfgrass plants over six-week experiment, based on a 0-9 scale, with 0 = brown, dead turf, 6 = minimally acceptable and 9 = optimal color, density, and uniformity. Error bars denote standard error of the mean (n=4)

Visual Quality

Our results demonstrated that irrigating zoysiagrass at > 60% of ET_a was sufficient to sustain acceptable turfgrass quality over the six-week study (Figures 2 and 8). Conversely, visual quality of 40% ET_a treatments gradually declined over the study, but fell to unacceptable levels after five weeks. Within two weeks of initiating treatments, turf receiving 20% ET_a declined rapidly to unacceptable levels characterized by rapid wilt and significant leaf firing throughout the entire turf canopy. Previous work has shown that irrigating to 80% ET_a twice weekly was necessary to maintain acceptable zoysiagrass quality (Fu et al., 2004) and irrigating above 73% ET_a three times weekly was necessary for maintaining adequate Kentucky bluegrass quality (Feldhake et al., 1984). Our results indicate that acceptable zoysiagrass quality may be achievable at even greater irrigation deficits if irrigation is supplied with greater frequency.

Photosynthesis and Shoot Growth

Canopy photosynthetic rates of fully watered (100% ET_a) plants exceeded that of all deficit irrigated treatments and decreasing irrigation amounts resulted in proportional reductions in photosynthetic rates (Figure 3). Rates of photosynthesis ranged from an average of 6.1 μmol m^{-2} s^{-1} at 100% ET_a to 0.8 μmol m^{-2} s^{-1} at 20% ET_a. This is not surprising, given that dry matter accumulation and transpiration have been shown to be intimately linked to leaf gas exchange through stomata (Sinclair et al., 1984).

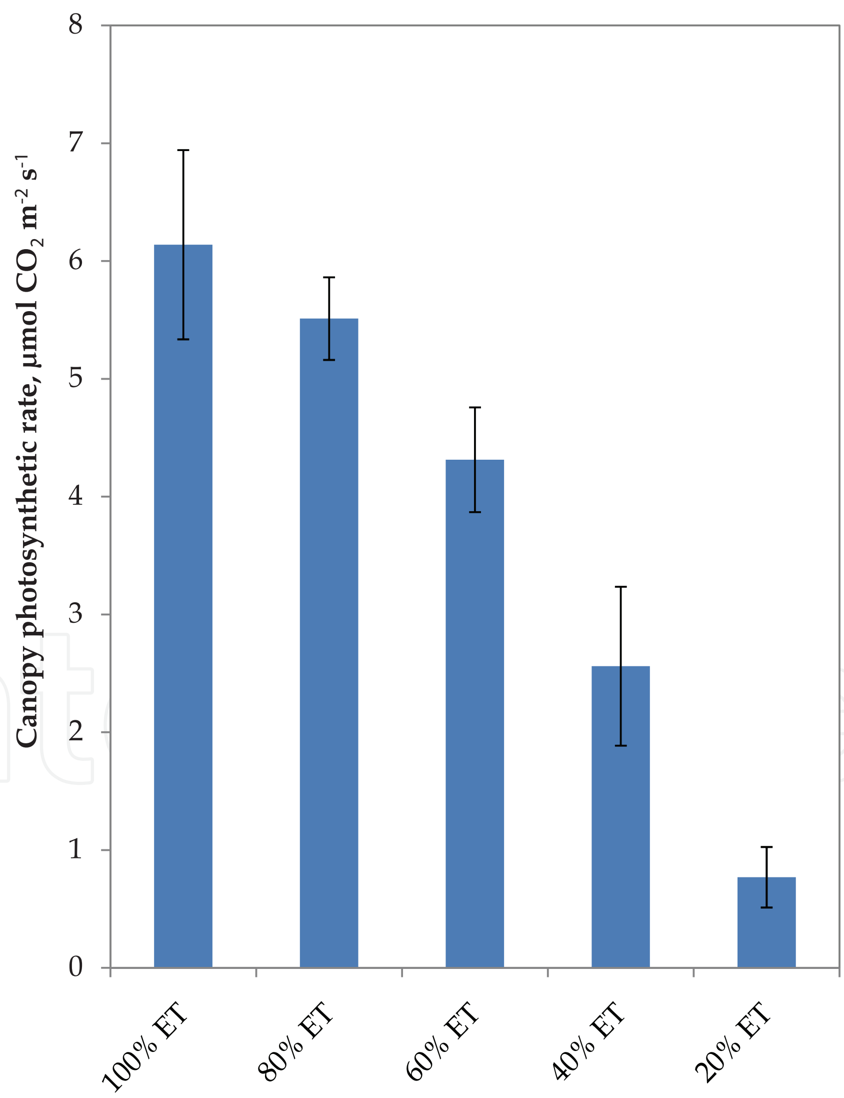

Fig. 3. Canopy photosynthesis rates measured at the conclusion of the six-week study. Error bars denote standard error of the mean (n=4)

Shoot growth is a process that is dependent on increases in cell volume, and thus, is generally highly sensitive to water deficit. Turfgrass shoot growth in this study was measured by weekly clipping collections, and was found to be progressively reduced with decreasing irrigation (Figure 4). Our data show that reducing irrigation to levels of 60% of ET_a, while causing little change in overall quality, led to as much as 25% reductions in shoot growth. Increased rates of turfgrass shoot growth have been correlated with higher turfgrass ET in a number of other warm and cool-season turfgrasses (Bowman & Macaulay, 1991; Shearman, 1986; Kim, 1983). Interestingly, while there was generally a proportional decrease in transpiration and shoot growth as deficits increased; shoot dry weights did not change between the 60% and 80% ET_a treatments. Thus, in terms of shoot growth, transpirational water use efficiency was greatest at 60% ET_a with this species (data not shown). From a practical standpoint, whereas soil water deficits may negatively affect field crop yields, moderate growth reductions in turfgrass sytems may actually be desirable, as they could result in less mowing requirements.

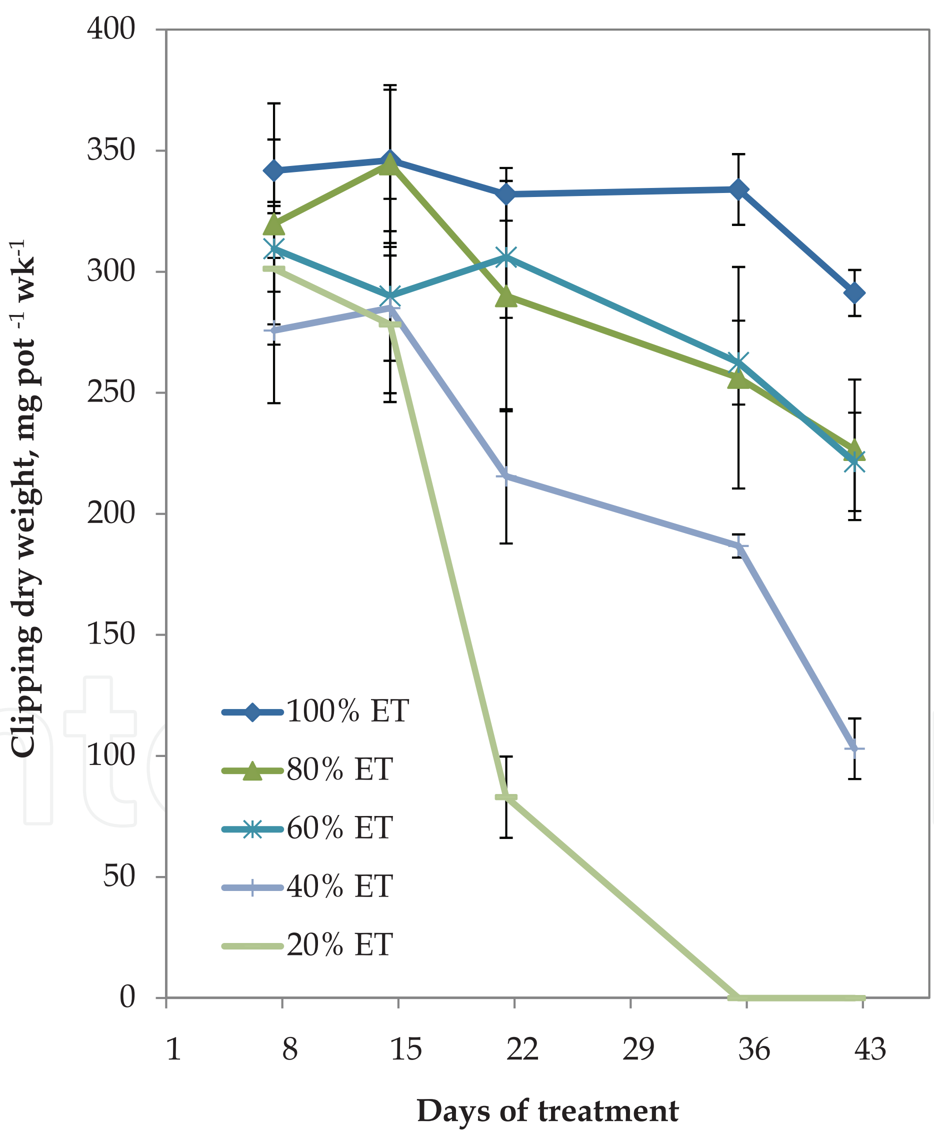

Fig. 4. Clipping dry weights collected weekly from 81 cm² pots. Error bars denote standard error of the mean (n=4)

Leaf Wilt and Firing

Leaf wilt and firing were the primary symptoms of plant water stress leading to quality loss in grasses receiving ≤ 60% of ET_a in the study (Figures 5 and 6). Leaf canopies of 20% ET_a plants declined most rapidly, with half of the canopy wilted within two weeks of initiating treatments, and becoming almost entirely fired by week six. 40% ET_a plants were nearly 50% wilted, with 30% of the canopy firing by week six. Only 5-10% of the canopy in 60% ET_a plants showed signs of wilt or firing; thus, quality was deemed acceptable throughout the study. Zoysiagrass irrigated at ≥80% ET_a never showed signs of wilt during any measurement period, indicating that soil moisture was sufficient to meet transpirational demand.

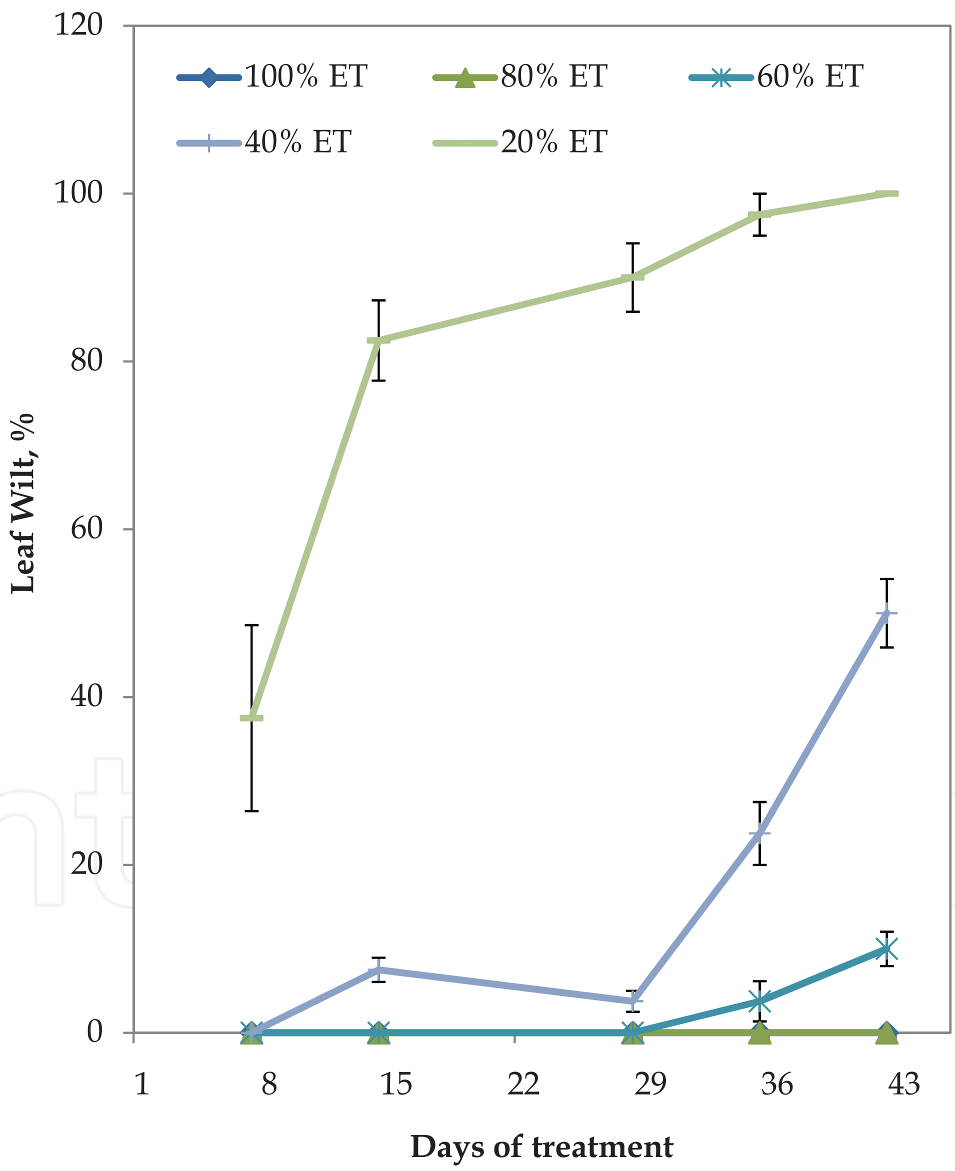

Fig. 5. Percentage of leaf wilt visible within the 81 cm^2 turfgrass canopy. Measurements were obtained during mid-afternoon hours on cloudless days. Error bars denote standard error of the mean (n=4)

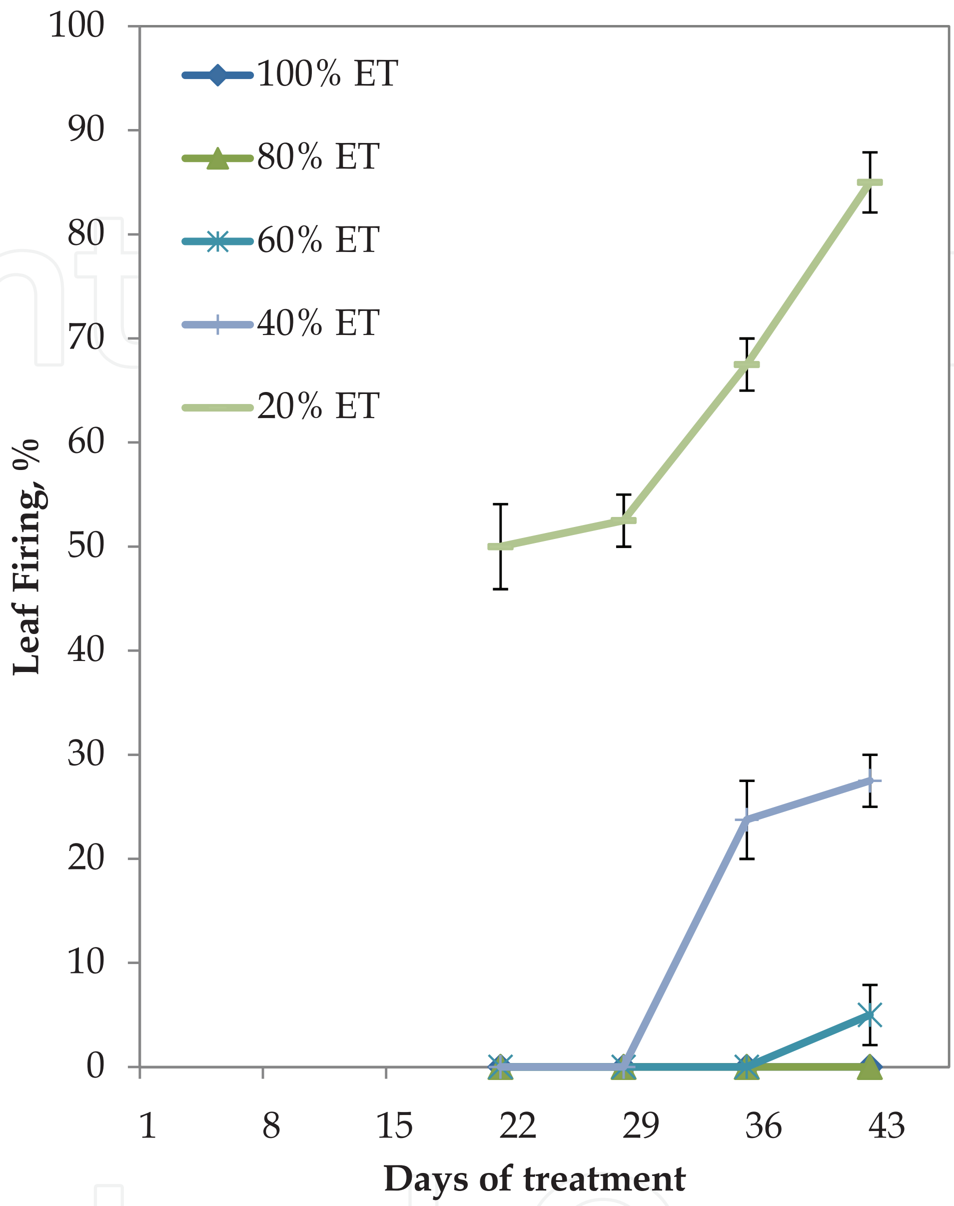

Fig. 6. Percentage of leaf firing visible within the 81 cm^2 turfgrass canopy. Measurements were obtained during mid-afternoon hours on cloudless days. Error bars denote standard error of the mean (n=4)

Reflective Heat Load

A substantial amount of incident solar radiation is converted to latent heat during the transpiration process. Therefore, vegetated surfaces such as turfgrass systems possess significant cooling capacity and play a critical role in heat dissipation within urban areas. It has been reported that green turfs and landscapes can save energy by reducing the energy input required for interior mechanical cooling of adjacent homes and buildings (Johns & Beard, 1985). Decreasing irrigation levels for water conservation conserves resources and maintenance requirements, but it also is likely to substantially impact reflective heat loads. Over the five sampling dates, we observed up to a 16 °C increase in canopy temperatures from fully irrigated to 20% ET_a irrigated turf (Figure 7). Interestingly, this heat load difference was reduced by half when irrigation was only slightly increased to 40% ET_a, due to the presence of significantly more green vegetation (Figure 8). Our data for zoysiagrass are similar to those of Feldhake et al. (1984), who reported a 1.7 ºC increase in Kentucky bluegrass canopy temperature for each 10% reduction in ET. While a non-irrigated control treatment was not used in this study, it seems likely that even greater heat loads would result from turf receiving no irrigation, as no living vegetation would likely be present. From a practical standpoint, these data suggest that large-scale landscape deficit irrigation practices, such as those mandated through municipal water restrictions, could contribute to significantly increased surface temperatures.

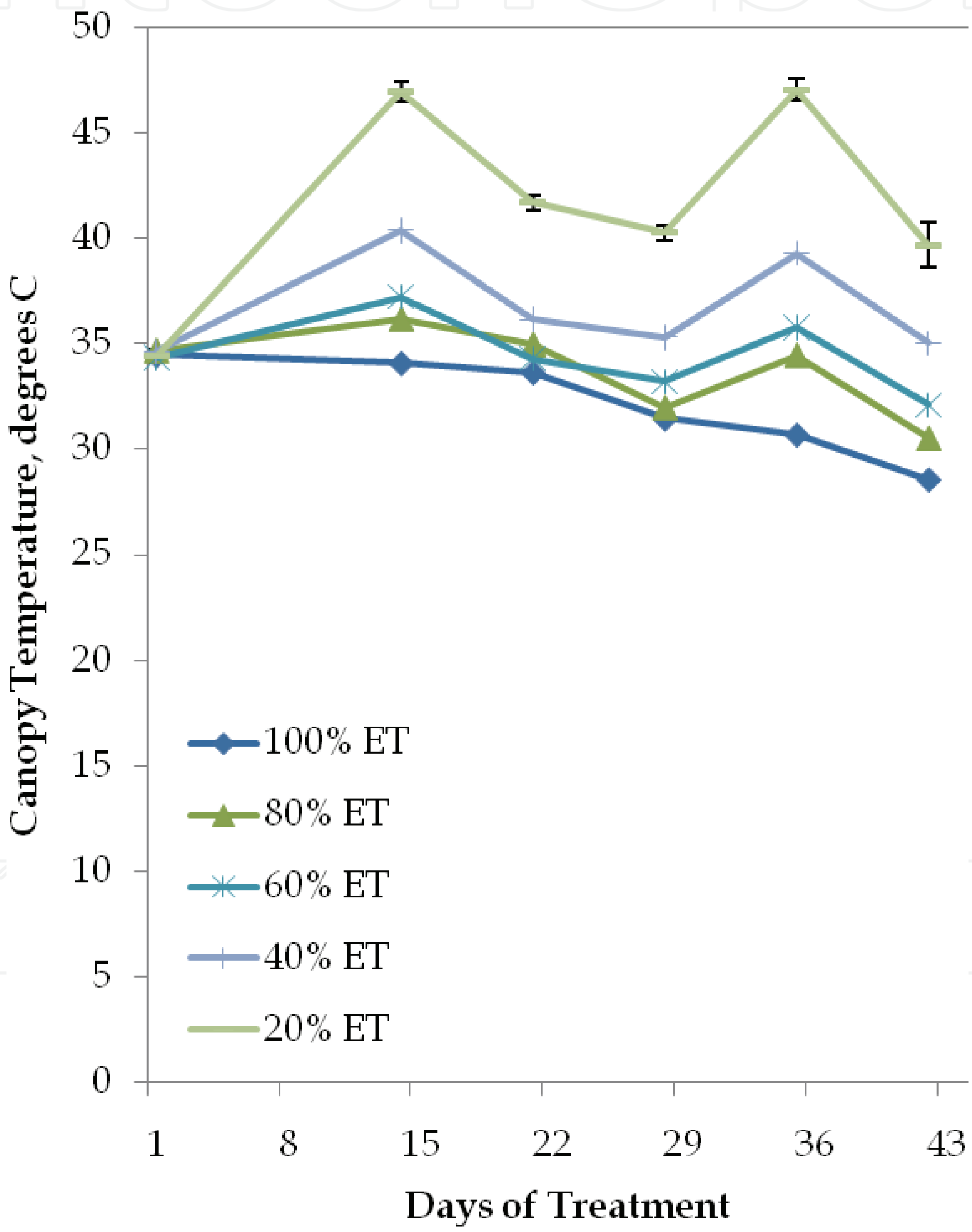

Fig. 7. Canopy temperatures within the irrigation treatments. Measurements were obtained during mid-afternoon hours on cloudless days. Error bars denote standard error of the mean (n=4)

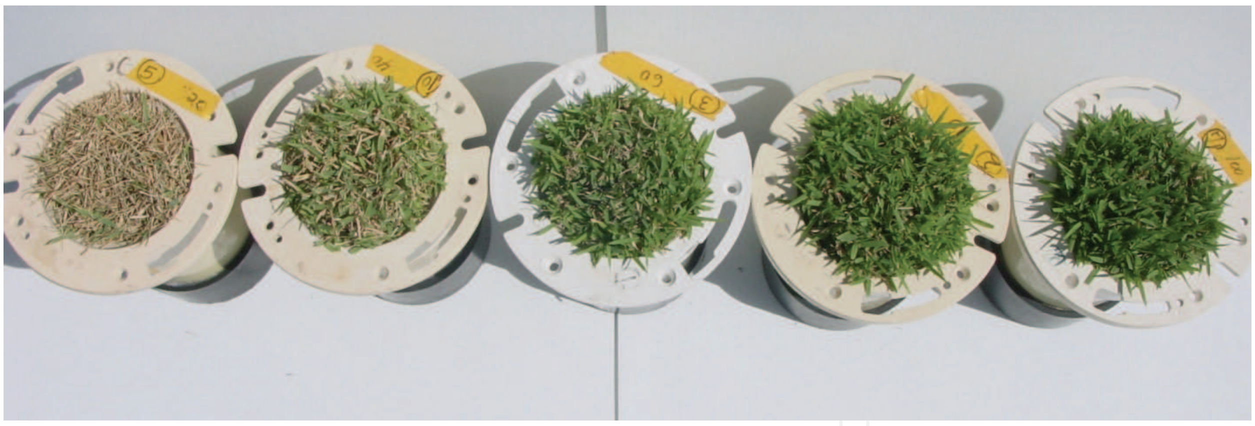

Fig. 8. Visual appearance of 'Empire' zoysiagrass following six weeks of deficit irrigation, applied daily. (From left to right: 20% ET_a, 40% ET_a, 60% ET_a, 80% ET_a, and 100% ET_a)

Fig. 9. Portable chamber system for measuring canopy gas exchange

4. Conclusions

On the basis of our results, deficit irrigation can be a useful means of conserving water in the management of turfgrass. Irrigating zoysiagrass at up to a 40% deficit (60% ET_a) was sufficient to maintain acceptable turfgrass quality over a six-week period. Zoysiagrass response to the deficit irrigation included a reduction in evapotranspiration and photosynthetic rates, as well as shoot growth reductions. Such effects on shoot growth may be viewed as beneficial, as they would likely result in fewer mowing requirements. Our results suggest that irrigating this species at >40% irrigation deficits would not be advisable, as significant leaf wilt and firing occurred which negatively affected the appearance of the turf canopy and produced less-than-acceptable visual quality of the turf. While we were able to maintain acceptable quality at these levels with daily watering, it is likely that less frequent irrigation scheduling (2 or 3 days per week) might result in greater loss of quality at similar levels of ET replacement, due to longer periods of water stress encountered. An important consideration with deficit irrigation practices is the increasing reflective heat loads that are generated with diminishing amounts of irrigation. Canopy temperatures in this study progressively increased with greater deficits to a maximum increase of 16^{o} C between 100% and 20% ET_a plants. This is an important consideration that could have large-scale implications on the surface temperatures and human comfort levels within urban environments.

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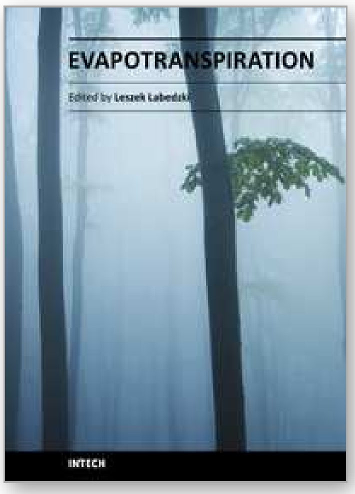

Evapotranspiration
Edited by Prof. Leszek Labedzki

ISBN 978-953-307-251-7
Hard cover, 446 pages
Publisher InTech
Published online 16, March, 2011
Published in print edition March, 2011

Evapotranspiration is a very complex phenomenon, comprising different aspects and processes (hydrological, meteorological, physiological, soil, plant and others). Farmers, agriculture advisers, extension services, hydrologists, agrometeorologists, water management specialists and many others are facing the problem of evapotranspiration. This book is dedicated to further understanding of the evapotranspiration problems, presenting a broad body of experience, by reporting different views of the authors and the results of their studies. It covers aspects from understandings and concepts of evapotranspiration, through methodology of calculating and measuring, to applications in different fields, in which evapotranspiration is an important factor. The book will be of benefit to scientists, engineers and managers involved in problems related to meteorology, climatology, hydrology, geography, agronomy and agricultural water management. We hope they will find useful material in this collection of papers.