EVAPOTRANSPIRATION, CONSUMPTIVE WATER USE, AND RESPONSES TO SELF-IMPOSED DROUGHT OF THREE WARM SEASON GRASSES GROWN IN A SEMI-ARID REGION

By

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DEDICATION

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (*Continued*)

Page

LIST OF FIGURES

LIST OF TABLES

Table Page

ABSTRACT

Evapotranspiration rates (ET) and consumptive water use (CWU) were measured for three desert turfgrasses using weighing lysimeters with a calcined clay growth medium. Water use rates were compared over a two-year study for 'Sea Isle I' seashore paspalum (*Paspalum vaginatum*) and A138 desert saltgrass (*Distichlis spicata*), along with 'Tifway' bermudagrass (*Cynodon* dactylon x *Cynodon transvaalensis*). Saltgrass showed elevated leaf canopy temperatures for extended periods before exhibiting visible wilt symptoms while 'Tifway' bermudagrass and seashore paspalum wilted readily, even at relatively high soil water contents. Saltgrass transpired for 11.9 d on average before drought stress was observed. Seashore paspalum maintained leaf turgor, on average 5.6 d without irrigation, whereas 'Tifway' bermudagrass averaged 4.0 d before requiring irrigation. The two-year average K_c values for three grasses before self-imposed drought was expressed by visible leaf wilting were 0.85, 0.79, and 0.74, for A138 saltgrass, 'Sea Isle I' seashore paspalum, and 'Tifway' bermudagrass, respectively.

CHAPTER 1

INTRODUCTION

Turfgrass Water Use

All areas of the world experience natural cycles of drought, however, Arizona and the rest of the Southwest are particularly sensitive to drought impacts. In arid regions such as the Southwest, water is scarce even during years of above-average rainfall (Arizona Department of Water Resources, 2007a). Continued population increases coupled with drought conditions have placed increasing pressure on limited potable water resources in the Southwest.

Between 1990 and 2000 the western states of Arizona, Nevada, and California experienced an 18% increase in human population. In addition, eight of the nation's top ten fastest growing cities (100,000 or more population) since the 2000 Census lie in the western states of Arizona, Nevada and California (U.S. Census Bureau, 2004). This continued urbanization has increased competition for limited water resources prompting many municipalities and water agencies to initiate water conservation programs (Devitt et al., 1995). As a result, the need to conserve limited water resources applied to irrigated turfgrass has become increasingly important. Turfgrass water use has received much attention due to the amount of irrigation water that is required to maintain high quality turf. With nearly 400 golf courses in Arizona, this attention has prompted the Arizona State Legislature to implement water conservation programs that mandate water allotment limits to turf facilities with 4.0 ha (10 acres) or more of turfgrass landscaping. These allocations equal up to 1402 mm and 1494 mm of groundwater use per year per unit area of turf in the Tucson area and Phoenix area, respectively (Arizona Department of Water Resources, 1991a, 1991b). Golf course managers are now faced with maintaining high quality turf with less water.

As water costs rise, more accurate knowledge of evapotranspiration (ET) rates will become increasingly important in order to achieve greater efficiencies in irrigation practices and conservation efforts. In Texas, ordinances have been implemented that require residential and commercial builders to install turfgrass with summer dormancy capabilities (San Antonio Water System, 2005).

In addition, Arizona's groundwater is being extracted more rapidly than it is being replenished. The total annual groundwater overdraft in the Tucson Active Management Area (AMA) in 1995 was close to 164,000 acre-feet, and remains a serious problem (Arizona Department of Water Resources, 2007b). Thus, alternative irrigation sources need to be sought. Restrictions by state and local governments on the use of potable water for landscape irrigation has led to the use of secondary water sources such as effluent or reclaimed wastewater for irrigation of large turf areas (Marcum, 2006). According to a survey of golf course superintendents in the Southwestern United States, 27% of surveyed courses currently irrigate with reclaimed water. Forty percent of those who had switched to reclaimed water in Arizona did so due to mandates (Devitt et al., 2004).

Reclaimed water is the one increasing water source in Arizona, and as population continues to increase and domestic water use demand increases, more treated wastewater will be available (Arizona Department of Water Resources, 2007a). Use of reclaimed water in place of potable water for irrigating landscapes has the potential to relieve pressure on fresh water resources, however, the use and reuse of water can result in accelerated salt accumulation in the soil. Most mineral salts are not removed through common wastewater processes (Rebhun, 2004). Furthermore, soluble salts such as sodium chloride (NaCl) are concentrated when water is used for evaporative cooling and are therefore present in elevated concentrations in reclaimed water. Following most water treatment processes, sodium chloride is the major remaining chemical compound in reclaimed water that can be harmful to plants (Pepper and Mancino, 1994). As a result, salt tolerance is particularly important for grasses irrigated with reclaimed water.

The objectives of this study were to (i) evaluate the comparative non-stress ET rates, as well as (ii) compare water use under stress conditions and investigate drought resistance (avoidance, tolerance) of 'Sea Isle I' seashore paspalum and A138 saltgrass versus the current golf and sports industry standard cultivar 'Tifway' (Tifton 419) (*Cynodon dactylon* x C. *transvaalensis L. Pers.*) hybrid bermudagrass. Another objective was (iii) to investigate canopy temperatures in order to model turfgrass stress for the three studied grasses. Measured criteria included unstressed water requirements from field capacity and comparative drought resistance, using weighing lysimeters and infrared thermometry. Water use rates and leaf canopy temperatures were compared to evaluate the potential drought-tolerant turfgrasses under conditions of plant-dependent soil moisture depletion, either detecting drought avoidance or drought tolerance responses. This knowledge would allow the identification of grasses that may persist with reduced water inputs.

CHAPTER 2

LITERATURE REVIEW

Evapotranspiration and Consumptive Water Use

Turfgrass water requirements are based on water use rates and may be quantified through measurement of evapotranspiration rate (DaCosta and Huang, 2006). Evapotranspiration (ET) can be defined as the movement of water from the earth's land surface to the atmosphere in vapor form (from the combined processes of evaporation from soil and plant surfaces and transpiration through plant canopies) (van Bavel, 1961). The difference between evaporation and transpiration rests in the path by which water moves from the soil to the atmosphere. In soil evaporation, water moves directly from the soil surface to the atmosphere. Conversely, water lost through transpiration must enter the plant via the roots and pass through the foliage where it is vaporized and lost to the atmosphere through stomata on the leaf surface (Brown, 2000).

Brown (2000) summarized the factors affecting ET and their relative contribution to ET rates. Four critical factors affect the rate of ET for a given environment, including soil moisture, plant type, stage of plant development, and weather.

First, adequate soil moisture must be present in order for ET to take place. Secondly, plant type influences the rate of ET. Plants native to the Southwest are well adapted to desert conditions, requiring less water than many grasses and non-native plants (Brown, 2000). Morphological and growth-characteristics such as shoot and leaf density, horizontal leaf and shoot orientation, leaf extension rates, and leaf width have also been attributed to differences in ET rates (Ebdon and Petrovic, 1998; Ebdon et al., 1998). Thirdly, stage of plant development plays a critical role in determining the rate of ET. The size of the plant and activity of the plant will determine how much water is required for growth. Dormant and semi-dormant plants require and thus, use less water than actively growing plants. Size is also of importance, as large plants with dense canopies require more water than small, sparse-canopied plants.

Lastly, four weather parameters, including solar radiation, wind speed, humidity, and temperature all affect the rate of ET. Solar radiation has the greatest impact on ET as it contributes the energy available for the evapotranspiration process. Wind speed is also a critical factor as it transports heat from adjacent surfaces (advection) and accelerates evaporation by enhancing transfer of water vapor from moist vegetative surfaces to the dry atmosphere. Humidity and temperature determine the "drying power of the atmosphere." This variable is termed the vapor pressure deficit (VPD) and "estimates the difference (or gradient) in vapor pressure (concentration of water vapor) between the moist vegetation and the drier atmosphere above" (Brown, 2000). Temperature is the final weather parameter affecting ET. Temperature affects both VPD and advection. In addition, the temperature of vegetation affects how much energy must be present for ET to take place, as less energy is required to vaporize warm as opposed to cool water (Brown, 2000).

The applied water requirements of turfgrass in the Desert Southwest are relatively high due to the arid climate, limited precipitation, and mild winter temperatures that allow for year round culture of turfgrass (Brown et al., 2001). Thus, accurate estimates of evapotranspiration rates of individual turf species are necessary for efficient water management. Comparisons of ET rates among turfgrasses could also allow for a more accurate estimate of potential water savings associated with the replacement of one species with another (Devitt et al., 1995). This knowledge would allow the identification of grasses that persist with reduced water inputs as well as allow for the development of efficient irrigation practices (DaCosta and Huang, 2006).

Various studies have evaluated turfgrass water use rates in the arid Southwest (Kneebone and Pepper, 1982; Kopec et al., 1991; Garrott and Mancino, 1994), but only limited research has been conducted on inland saltgrass (*Distichlis spicata)* and 'Sea Isle I' seashore paspalum (*Paspalum vaginatum*). Kopec et al. (2006) evaluated the ET and consumptive water use (CWU) of saltgrass clones A119 and A48, seashore paspalum, and 'Tifway' (Tifton 419) hybrid bermudagrass (*Cynodon dactylon* X *C. transvaalensis*) over two seasons under non-limiting soil moisture conditions. They found that seashore paspalum had both the highest ET rate and CWU in June and July in 2005, and May, June, and July in 2006. 'Tifway' bermudagrass and saltgrass A119 essentially had the same ET rate and CWU, excluding September 2005, when 'Tifway' had the lowest ET and CWU (Kopec et al., 2006). Ries et al. (2005) compared the relative water use rate of seashore paspalum (*Seashore Paspalum cv*. 'ASI-125'), hybrid bermudagrass (*Cynodon dactylon x Cynodon transvaalensis* cv. 'Tifgreen'), and tall fescue (*Festuca arundinaceae* cv. 'Jaguar') in weighing lysimeters over a seven month period (April-November). This study concluded that during periods of high ET_o (reference ET) and non-limiting irrigation, 'ASI-125' seashore paspalum and 'Tifgreen' bermudagrass had similar water use rates, and both used significantly less water than tall fescue. Calculated crop coefficients (K_c) using a modification of the Penman-Monteith Equation (K_c; actual plant ET relative to reference ET) ranged from a low of 0.60 for bermudagrass in April to a high of 1.12 for tall fescue in May. The average K_c values were 0.83, 0.83, and 0.99, for bermudagrass, seashore paspalum, and tall fescue, respectively (Ries et al., 2005).

Salaiz et al. (1991) studied evapotranspiration rates among 10 cool-season creeping bentgrass (*Agrostis palustris* Hudson) cultivars. Evapotranspiration rates ranged from 3.2 mm d^{-1} to 10.7 mm d^{-1} during the growing season (May-October) in this two-year study. Evapotranspiration rates differed among cultivars by as much as 84% on one measurement date in year one and 39% on one measurement date in year two. These results indicate a large variability in evapotranspiration rates among cultivars and the potential for selection and development of creeping bentgrass cultivars with reduced ET rates. Garrot and Mancino (1994) determined the water requirements of three high-maintenance bermudagrasses ('Texturf-10', Tifgreen, and Midiron) growing under arid field conditions subjected to deep infrequent irrigations. In this study, turf was re-irrigated only after visible wilt was observed. Mean annual consumptive water use for 'Texturf-10', 'Tifgreen', and 'Midiron' was 929.2 mm, 873.1 mm, and 834.2 mm, respectively. Crop coefficients based on a modified Penman Equation followed the same order of the mean consumptive water use for the three varieties, ranging from 0.57 for 'Midiron' to 0.64 for 'Texturf-10'.

Studies have also been conducted to investigate the water use of various grasses under deficit irrigation. Deficit irrigation is the intentional irrigation of a plant with less than its maximum potential water demand, to conserve water and increase water use efficiency (Kirda, 2002). DaCosta and Huang (2006) studied the minimum water requirements of creeping (*Agrostis stolonifera* L.), colonial (*A. capillaris* L.), and velvet (*A. canina* L.) bentgrasses managed under fairway conditions. In this study turf plots were irrigated at 100, 80, 60, and 40% of the actual evapotranspiration (ET_a), as determined by mini-lysimeters. They found that irrigating at 100% ET_a was not necessary to maintain acceptable turfgrass quality and that minimum water requirements varied among species and time of year. Their research indicated that in order to maintain acceptable turf quality, colonial bentgrass required 80–100% ET_a, while creeping and velvet bentgrass quality remained acceptable at 60–80% ET_a.

Lysimetric Measurements of ET Rates

Lysimeters are measurement devices used in soil physics, hydrologic, irrigation water requirement, and water quality research to measure the soil water balance and to separately determine the vertical water fluxes and/or soil water solute chemical transport (Howell, 2004). More specifically, a lysimeter is a container of soil or other root zone media, through which water infiltrates in such a way that its quantity or quality can be measured. Lysimeters are particularly valuable in transpiration and evapotranspiration research (Ben-Gal and Shani, 2002). Their use in studying moisture changes in a confined body of soil is the only practical method for precise measurement of evapotranspiration rates (van Bavel, 1961). Lysimeters have been used since the late 19th century to study vegetative water use (Young et al., 1996).

Distribution of ET can be difficult to measure in the field with variations in soil physical properties, soil moisture regimes, and vegetation types, making lysimeters a suitable method for measuring ET rates under field conditions (Rogowski and Jacoby, 1977; van Bavel, 1961). However, there are certain requirements of the construction and operation of lysimeters that must be met in order to achieve accurate evapotranspiration measurements.

The following limitations of lysimetric measurements of evapotranspiration were discussed by van Bavel, 1961. First, confining a body of soil within a lysimeter prevents lateral moisture exchange and holds all percolate for precise measurement. However, the natural flow and distribution of water is prevented within a lysimeter. Secondly, following the irrigation event of a lysimeter, a zero-pressure plane exists resulting in a different moisture tension and moisture content than the surrounding area. This can result in more available water for evapotranspiration and different root zone development of the crop grown within the lysimeter. These limitations can possibly be avoided by including a tensioning device at the base of the lysimeter and constructing the lysimeter so that the depth is well below the root zone. Thirdly, the lysimeter should contain a representative profile so that moisture retention, moisture transmission, and root distribution is representative of the surrounding area. Lastly, uniform conditions surrounding the lysimeter should be present. Therefore, the lysimeter should be surrounded by a considerable area planted, watered, fertilized, and managed in the same manner as the lysimeter (van Bavel, 1961).

The use of lysimeters has been common in recent years in order to evaluate irrigation needs of plants. Two monolith weighing lysimeters were used at The

University of Arizona Karsten Turfgrass Research Facility in order to measure ET of 'Tifway' bermudagrass in the summer months and overseeded 'Froghair' intermediate ryegrass (*Lolium multiflorum x L. perenne*) during the winter (Brown et al., 2001). They found that bermudagrass K_c values ranged from 0.78 during June to 0.83 in September, with K_c values for intermediate ryegrass ranging from 0.78 in January to 0.90 in April. They also found that summer K_cs varied in relation to turf growth rate, whereas monthly variation of winter K_cs varied in relation to mean air temperature.

Kopec et al. (1988) used mini-lysimeters to estimate ET rates of six tall fescue cultivars as mowed turfs. There were significant ET differences among cultivars. ET differed by as much as 18%, and turf types demonstrated a 9% lower ET than forage types. Cultivars also varied in wilting tendency, capacity to meet ET demand, and extraction of available soil water. A similar study utilized mini-lysimeters to examine perennial ryegrass cultivar ET rates (Shearman, 1989). The cultivar 'Linn' exhibited a 20–33% higher water use than 'Prelude'. The results of this study were similar to those reported for tall fescue cultivars (Kopec et al. 1998), and creeping bentgrass cultivars (Salaiz et al. 1991). All of these studies suggest a potential for considerable water savings within a species through proper cultivar selection.

van Bavel (1961) used lysimeters to measure ET rates in the Eastern United States. Over several years this study demonstrated minor, if any, differences among the ET rates of corn, wheat, and forage bermudagrass. Maximum daily ET rate from corn was 4.597 mm and bermudagrass was 4.826 mm. For a 100-day period, the consumptive water use for corn and bermudagrass was 436.88 and 401.32 mm, respectively. The data in this particular study showed that the effect of crop morphology was not large and ET rates are primarily dependent upon meteorological factors when soil moisture is not limiting.

Drought Resistance and Salinity Tolerance

Another strategy to conserve water is the use of drought resistant turfgrasses with low water requirements that are capable of tolerating moderate periods of water stress. Drought is a major limiting factor for turfgrass growth in many arid and semi-arid areas (Huang and Fry, 1998). Arid and semi-arid regions are typically characterized by low soil moisture content, which is a cause of water stress in turfgrass (Reynolds, 2000). In the Southwest, where turf managers face the challenge of growing turfgrass with limited water amounts, poor water quality, and poor soils, selection and use of drought resistant turfgrasses can reduce the amount of irrigation water required.

The identification of water conserving and drought resistant turfgrasses is extremely important for water conservation (Ebdon et al., 1998). For example, Desert saltgrass, a previously non-domesticated warm-season perennial grass native to arid, alkaline, and salt-affected soils has shown promise for development as a turfgrass (Christensen and Qian, 2005).

Drought resistance consists of the following categories: drought avoidance, drought escape, and drought tolerance (Beard, 1989; Kenna and Horst, 1993). Drought avoidance can be defined as the “ability of a plant to avoid tissue damage in a drought by postponement of dehydration” (Kenna and Horst, 1993). Drought escape is the ability of a plant to become dormant during drought, or to complete its life cycle before soil moisture is depleted (Kenna and Horst, 1993). Lastly, drought tolerance is attributed to a plant's internal cellular mechanisms, or the ability of cells to maintain positive turgor pressure as external water potentials decline (Ervin and Koski, 1998). Turfgrass species possessing (i) deep and extensive root systems and (ii) morphological and physiological traits that reduce ET may exhibit improved drought resistance (Ebdon and Petrovic, 1998).

Various studies have investigated both cool-season and warm-season turfgrass drought resistance. The growth responses of three major sport turfgrasses, creeping bentgrass, rough bluegrass (*Poa trivialis*), and perennial ryegrass were compared in terms of shoot length, root length, dry matter, and percent green canopy cover under salinity and drought stress conditions (Pessarakli et al., 2005). Significant reductions in the amount of green canopy cover due to drought and salinity stress were observed. Bluegrass demonstrated the highest degree of stress sensitivity with the greatest reductions in green cover, averaging 44-60%. Ryegrass demonstrated an 8-36% reduction, whereas bentgrass proved the most salt/drought tolerant, exhibiting a 3-12% reduction in green canopy cover.

An additional study examined drought tolerance of 21 saltgrass clones and bermudagrass in a greenhouse study (Pessarakli et al., 2001). During a four-month drought period, plant dry matter production and percent green color retention were assessed to determine the response of the grasses to drought. This study found that A137 and A138 (Arizona accessions) were the most drought tolerant of the tested clones, while

C66 (Colorado accession) was the least drought tolerant. C66 showed a 50% reduction in clipping weights after seven weeks of drought, whereas A138 sustained ten weeks of drought before showing a similar reduction. The majority of saltgrass accessions were more tolerant to drought stress than bermudagrass, when tested under self-imposed drought using calcined clay as the root zone media.

Canopy Temperature Based Irrigation Scheduling

Canopy temperature assessment measuring sensible heat is based on the principle that plant transpiration, in arid regions, cools the leaf surface below the ambient air temperature under non-limiting soil moisture conditions. Since plant transpiration is reduced as soil water becomes limiting, elevated leaf temperatures are associated with decreases in plant available soil moisture (Jackson, 1982; Jalali-Farahani et al., 1993).

The development of commercial versions of infrared thermometers (IRTs) used to measure emitted thermal radiation has prompted the use of these sensors for determining canopy temperature and scheduling irrigations. Current techniques used for scheduling irrigations tend to be inefficient by promoting over-watering (Throssell et al., 1987). To efficiently use water resources it is essential that turfgrass managers optimize the timing and amount of irrigation applied to turfgrass.

Idso et al. (1977) and Jackson et al. (1977) introduced the concept of the "Stress Degree Day" (SDD), which is the plant canopy temperature (T_c) - ambient air temperature (T_a), (differential, ΔT) at the time of maximum canopy temperature calculated as: $SDD_{pos} = \Sigma(T_c - T_a)$.

The SDD parameter can be used as an indicator of a plant's water status. Assessment of plant canopy temperature with an IRT has potential to provide an alternative index for irrigation scheduling. Direct measurement methods such as tensiometers, resistance blocks, and neutron probes are capable of providing direct soil moisture estimates, but have disadvantages in that they are site specific, may not represent the field soil moisture, and are incapable of predicting water use. Ideally, an irrigation scheduling technique should use the crop as an indicator of moisture stress and the soil to determine the amount of water to apply (Geiser et al., 1982).

However, there are some shortcomings of the abovementioned technique. Canopy temperature measurements are sensitive to immediate weather fluctuations. In order to reduce these fluctuations, measurements of net radiation, soil heat flux, wind speed, and aerodynamic and canopy resistances must be accounted for (Stockle and Dugas, 1992; Gates, 1968). IRTs are also sensitive to the view angle of the infrared sensor and its relation to the solar zenith angle (Fuchs, 1990). For these reasons the use of IRTs for measurement of row crop canopy temperatures has proved difficult (Jackson et al., 1981; Howell et al., 1984). Moreover, the measurement of plant canopy temperature allows for the determination of timing of irrigations but not irrigation amounts (Nielsen, 1990).

As stated earlier, the stress-degree day parameter can be influenced by environmental factors other than soil moisture, such as wind speed, net radiation, and air vapor pressure (Gates, 1968). The crop-water stress index (CWSI) was developed in order to normalize the stress-degree day parameter for environmental variability (Idso et al., 1981; Jackson et al., 1981). The simplest empirical model is based on observations of canopy – air temperatures of well-watered turf and air vapor pressure deficit producing a linear relationship referred to as the *non-water stressed baseline* or lower limit (Jalali-Farahani et al., 1993).

CHAPTER 3

MATERIALS & METHODS

ET and Consumptive Water Use

The following experiment was conducted at The University of Arizona Karsten Turfgrass Research Facility (32° 16' 49" N, 110° 56' 45" W) (KTRF) located at Tucson, AZ. The KTRF resides in an alluvial valley 713 m above mean sea level. Tucson has a semiarid climate, with an annual precipitation of approximately 300 mm. In June 2005, 'Sea Isle I' seashore paspalum, A138 saltgrass, and 'Tifway' bermudagrass were established in 3 m x 3 m plots. The soil at the site is classified as an Agua sandy loam (coarse-loamy over sandy, mixed, calcareous, thermic Typic Torrifluvent) (Appendix A). Plots were arranged in a randomized complete block with four replications (Figure 1).

A 0.03 ha turf block containing the lysimeters was managed in the same manner as the lysimeters. The turf block was surrounded by an area of tall fescue (*Festuca arundinaceae)* that extended approximately 10 m to the north and 5 m to the east. An additional 30 m of mixed fetch existed to the west and 40 m south of the lysimeter turf block. The block arrangement was designed to account for fetch distance surrounding the lysimeter plots and immediate boundary.

The three grasses used in the study were established vegetatively in weighing lysimeters in the summer of 2005. The lysimeters were constructed of 25.4 cm diameter poly-vinyl chloride (PVC) tubing cut to a 91.4 cm length.

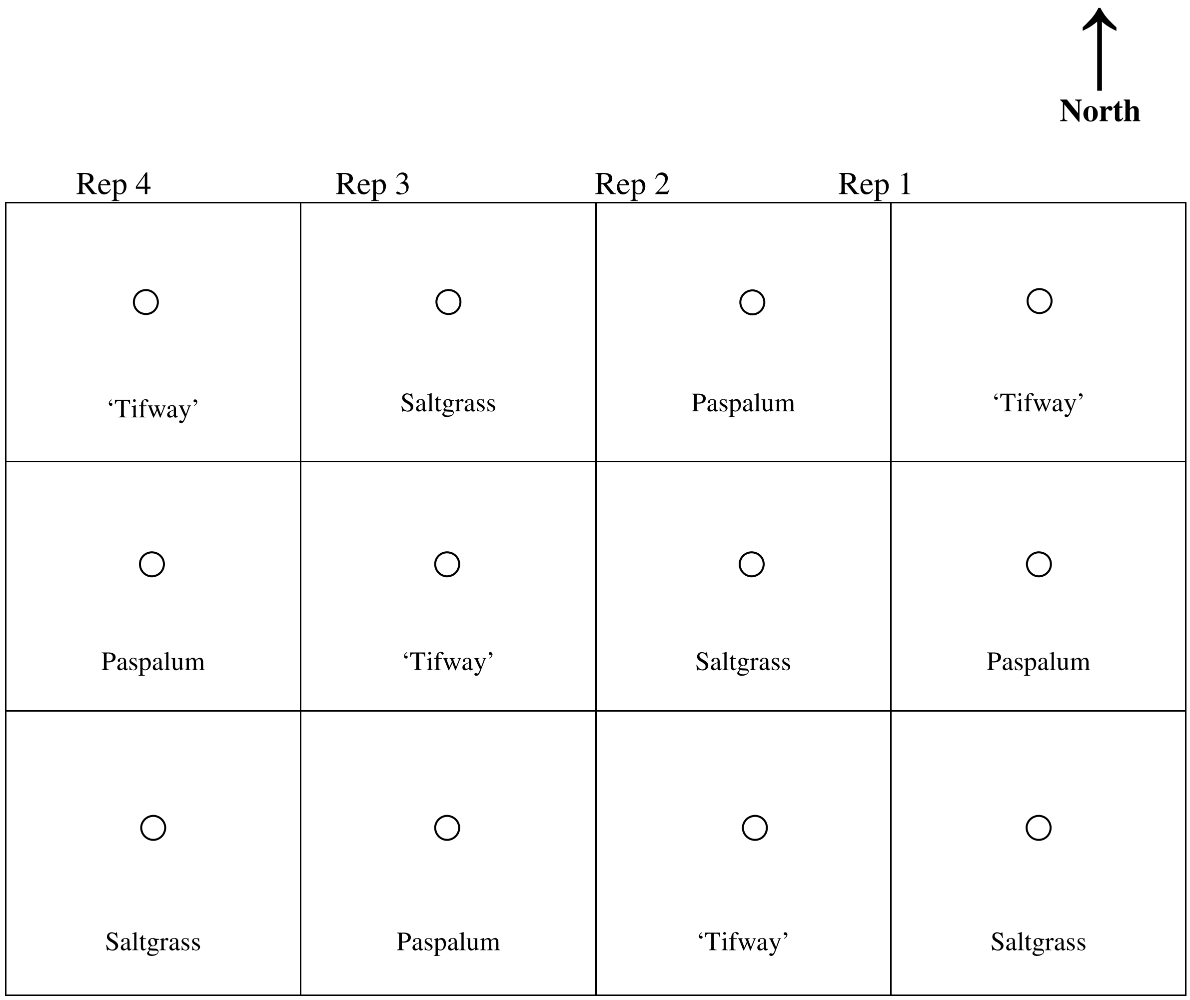

Figure 1. Plot layout of cultivar and rep location.

The evaporative surface of each lysimeter was 506.4 cm^2. The headway (distance between lysimeter rim and calcined clay level) was set at 1.58 – 1.90 cm. Plastic bottoms glued to the inside of the lysimeter at 76.2 cm from the top rim defined the bottom of the root-zone (38500 cm^3 volume). The root zone shelf contained a ball-release valve that was opened for drainage when lysimeters were not in the test and closed for the duration of ET measurements, eliminating any loss of water by drainage. During ET measurements, lysimeters were inserted into a PVC casing in their respective plots and the base of the casing was adjusted using gravel so that the top of the lysimeter was level with the surrounding soil surface.

Lysimeters were filled with calcined clay (illite) root zone medium (Turface Pro League, Buffalo Grove, IL). Calcined clay, also known as fritted clay is coarsely milled, rotary kiln dried clay, used as a granular growth medium. Nearly 30 years ago, van Bavel et al. (1978) noted, “the material has a relatively low-dry bulk density, is non-cohesive, drains very rapidly, retains a large quantity of plant-available water, appears to be chemically inert, and can easily be washed off the roots.” Individual clay granules ranged from 1-2 mm in diameter. The bulk density of the calcined clay packed in the lysimeters was 0.60 g cm^{-3}.

ET was measured over multiple day periods or ‘cycles’. To initiate a ‘cycle’ all lysimeters were watered to saturation, allowed to drain overnight (~12 h) immediately adjacent to operative greenhouse cooling pads to reach field capacity. Lysimeters were weighed using a Sartorius EB150FEG digital readout scale (Sartorius AG, Goettingen, Germany) and then placed in their respective field liners. The scale model measures in 5 g increments. This translates to 0.098 mm of water loss as the lowest detectable limit. Lysimeters were manually lifted daily from the plots using a two person pole lifting mechanism attached to a wooden disc with three hardware quick-clip carabiners that attached to three cables fixed to the lysimeter, 120° apart.

ET was measured daily during the pre-dawn hours. ET was calculated based on decrease in lysimeter mass divided by the surface area of the lysimeter. Measurements of ET continued until the plants showed visible or measurable signs of stress (leaf curling, wilting, elevated leaf temperature, or change in leaf color). At this point the stressed lysimeters were removed from the test and returned to non-limiting water conditions. Each of the lysimeters was maintained in the trial until it showed signs of water stress. A 'cycle' was terminated when the last lysimeter, regardless of grass type, was removed due to visible drought stress (wilting). At the beginning of each cycle, lysimeters were selected at random regardless of previous selection/use, to eliminate any potential bias of heat or drought hardening.

Plots and the surrounding turf area were mowed at 1.58 cm using a 56 cm walk behind reel mower. Lysimeters were mowed at 1.58 cm using electric hand held Stewart Shearmaster Model EW311A sheep shears (Jarden Consumer Solutions, Boca Raton, FL). Plots and lysimeters were mowed three times weekly during the summer at or near the time of lysimeter extraction. Lysimeters were removed, weighed, and trimmed by block. As each block was removed, the plot was mowed one pass wide (56 cm) over the centerline of the lysimeter liners, followed by the immediate return of the weighed and trimmed lysimeter. This was repeated for each of the four-replication blocks.

Immediately after the last lysimeter was re-installed in its casing, the remaining plot area was mowed. All activity was performed at or near pre- dawn conditions when atmospheric demand for water was minimal. Lysimeter extraction, weighing, and installation on non-mow days took approximately 30 minutes or less, with two workers. On days when mowings were performed, three workers completed these tasks entirely in 45 minutes or less. Plots and lysimeters were mowed one to two times per week during the fall and early spring. Clippings were not captured during mowing events.

Precipitation was recorded (Appendix B) in Cal-Poly catch cans surrounding the plots. Rainfall events were handled in one of three ways.

(i) ET adjustments were made by subtracting the amount of precipitation recorded from the lysimeter weight. (ii) In the anticipation of a rainfall event after dusk, lysimeters were covered with five-gallon pales to avoid any rainfall from reaching the lysimeters. Lastly, (iii) several dry down cycles had to be terminated due to high amounts of rainfall and flooding.

Reference ET (ET_o) was obtained from an Arizona Meteorological Network (AZMET) weather station located approximately 75 m southwest of the research site over well watered tall fescue maintained at a height of 8 cm. The AZMET ET_o referenced in our study is computed by the Original AZMET Equation (Brown, 1998). ET measured in lysimeters was compared with ET_o to estimate realized crop coefficients ($K_c = ET/ET_o$). Field biases for K_c determination were minimized by using the nearest hourly ET_o assigned to the removal, weighing, and re-installation of lysimeters based on a per field replication basis.

Leaf Canopy Temperature Measurements

Leaf canopy (T_c) and ambient air (T_a) temperature measurements were recorded every day between 1130 and 1300 hours (local standard time) on most days with clear-sky or steady-overcast conditions. Canopy temperatures (°C) were measured using an Everest Model 210 portable hand-held infrared thermometer (Everest Interscience, Tucson, AZ). The instrument has a field of view of 15° (can be adjusted to 4°), a sensing window of 10.5 to 12.5 µm, and a resolution of 0.1°C. The emissivity was set to 0.98. In each measurement the infrared thermometer was held above the plant canopy at an angle of approximately 35°- 40°above the horizontal, at an approximate distance of 0.3 m from the lysimeter turf surface. Midday temperature measurements were taken at eight different locations (4 from the east, 4 from the west) on each lysimeter and averaged to provide a mean measurement for each lysimeter. For each lysimeter, air temperatures were measured 90 cm above the soil surface using a Psychro-Dyne dry-bulb aspirated psychrometer (Instruments for Industry Inc., Ronkonkoma, NY). Air temperatures were subtracted from the canopy temperatures to form the difference $T_c - T_a$. The stress-degree parameter (SDD) was calculated as the sum of $T_c - T_a$ (positive values) for each day until a lysimeter was removed due to drought stress. The critical point model (CPM) was based on the $[T_c - T_a]$ as a single measurement on the final day the lysimeter was in the test before being removed due to visible drought stress. Immediately following leaf temperature measurements, visible wilt symptoms were evaluated using a 1 to 6 scale based on severity of leaf curling, with 1 = none, 2 = slight, 3 = slight-moderate, 4 = moderate, 5 = moderate-severe, and 6 = severe. Percent wilt of the turf canopy was also evaluated based on a scale of 0-100%. Lysimeters were removed when the turf exhibited moderate wilt (wilt rating = 4.0).

Between dry-down cycles, lysimeters were mowed on the same schedule and nutrient requirements of the grasses within the lysimeters were met by semi-weekly application of 2000 ml of ½ strength Hoagland's nutrient solution (Hoagland and Arnon, 1950). This provided and equivalent nitrogen rate of 0.22 kg N ha^{-1}. Monthly applications of (48 kg N ha^{-1}) ammonium sulfate nitrogen fertilizer were applied with a drop spreader. Bimonthly foliar applications were made of iron (18 kg Fe ha^{-1}) (ferrous sulfate). Plots were aerified using a Ryan Greensaire 24 (Jacobsen, Charlotte, NC) with 12 cm knife tines between cycles and prior to irrigation events. Heritage fungicide (Syngenta Professional Products, Greensboro, NC) was sprayed on lysimeters to the point of runoff using a rate of 3 g in a 3 L solution using a hand pump sprayer, approximately every three weeks. Heritage was applied at the field rate of 0.01 kg ha^{-1} on three occasions in early, late July, and mid-August in 2006. It was again applied at the same rate on two occasions in 2007, in mid-July and mid-August. Prior to the initiation of a DDC, field plots were irrigated using a split application over two to three consecutive days before beginning of each cycle. 5 to 7 cm of water was applied during this period to saturate field, provide deep soil moisture, and to allow field to reach field capacity. Tertiary reclaimed municipal wastewater (effluent) from Tucson was used as the irrigation water for the field plots. It was classified as having a medium to high salinity, and low sodium hazard, with an adjusted sodium adsorption ratio (SAR) of 4.7 (Ayers and Westcot, 1989).

Fraction of Available Water

The fraction of available-water (FAW) was calculated to correspond with each lysimeter weight in time. Prior to the experiment, all lysimeter construction weights were recorded as well as the mass of calcined clay used in each lysimeter. This allowed for the calculation of "mass-wetness". Beginning and endpoint volumetric water contents (VWC) were determined for the calcined clay material by the use of a Tempe Pressure Cell at -0.10 bars and a WP4 Dewpoint PotentiaMeter (Decagon Devices, Inc., Pullman, WA) at -15.0 bars. The fraction of available water was determined as:

$$\frac{\text{(VWC at time (t) – VWC at 15.0 bars)}}{\text{(VWC at 0.10 bars – VWC at 15.0 bars)}}$$

Dates of Experiment

Periods beginning with the first ET measurement until removal of all lysimeters due to stress are hereafter referred to as dry-down cycles (DDCs). From June–September 2006, five dry-down cycles were completed. Eight dry-down cycles were completed the following summer from May-September 2007. In year 1, ET measurements were taken 2 to 15 June (DDC1), 16 to 29 June (DDC2), 6 to 20 July (DDC3), 15 to 29 August (DDC4), and 31 August to 17 September (DDC5) 2006. In year 2, ET measurements were taken 1 to 12 May (DDC6), 15 to 24 May (DDC7), 30 May to 9 June (DDC8), 14 to 21 June (DDC9) 27 June to 9 July (DDC10), 18 July to 2 August (DDC11) 13 to 22 August (DDC12) and 1 to 14 September (DDC13) 2007.

Destructive Sampling of Lysimeters

Following the completion of the two-year test, lysimeters were destructively sampled for selected shoot and root characteristics. Measured parameters included shoot counts, leaf area, leaf-area index (LAI), and aboveground plant biomass (dry verdure weight) of four randomly selected lysimeters for each turfgrass. In addition, eight lysimeters of each treatment were harvested for root depth and profile observations. The numbers of shoots were counted using a 62 cm^2 disc and total estimated shoots were calculated by relating this measurement to the actual surface area of the lysimeter. Leaf area measurements were measured by passing ten random shoots through a LI-COR leaf area meter (LI-COR Biosciences, Lincoln, NE). Total estimated leaf area was calculated by multiplying the mean leaf area times the estimated number of total shoots and dividing by ten. Total estimated leaf area divided by the lysimeter surface area produced a leaf area index for each lysimeter. All data were subjected to the analysis of variance technique using SAS Software (SAS Institute Inc., Cary, NC) and means were separated by Duncan's new multiple range test, only if the mean square for treatments was significant at $p\text{-}value < 0.05$. Two-year combined analyses (where applicable) analyzed year as the whole plot, with grass and the grass x year interaction in the sub- plot analysis.

CHAPTER 4

RESULTS & DISCUSSION

In keeping with the objectives of this study and for purposes of clarification of results and discussion, this chapter is divided into two main sections.

Section I addresses plant responses of grass evapotranspiration rates and consumptive water use, as well as field derived K_c values when there was no turfgrass stress evident (i.e., all twelve lysimeters were present in test). Section II addresses total consumptive water use, realized K_c values, the number of days turfs transpired before showing wilt expressed drought stress, the fraction of available water at wilting point, and Stress-Degree Day and Critical Point Model results.

This format was selected to present major findings in a logical order relative to concurrent non-stressed ET results, and the additional responses of long term ET and consumptive water use until the completion of dry-down cycles.

Section I.

Non-Stress Comparisons

Evapotranspiration Rate

For the two year combined analysis, there were statistically significant differences in ET rates and consumptive water use (CWU) between ‘Sea Isle 1’ seashore paspalum, ‘Tifway’ bermudagrass, and A138 saltgrass in both years, with the main effects of years and grasses being statistically significant. There was not a significant grass x year interaction (Table 1). ET rate was significant on 34 of 47 comparative ET measurement days for the two-year test (Table 2).

In year I, the differences between grass ET rate were statistically significant ($p < 0.05$) on 19 of the 26 ET measurement days (Table 2). A138 saltgrass had the highest ET rates on 21 of 26 ET days. Saltgrass ET ranged from a low of 2.18 mm d^{-1} (Aug 16–17) to high of 8.81 mm d^{-1} (Jun 4–5). The seashore paspalum ET rate was between that of saltgrass and ‘Tifway’ on 19 of 26 ET measurement days. Paspalum had the highest ET rate on five days in year I, and was significantly ($p<0.05$) different from saltgrass and bermudagrass on five ET days. Paspalum ET ranged from 2.06 mm d^{-1} (Aug 16–17) to 8.39 mm d^{-1} (Jun 4–5). In year I, ‘Tifway’ bermudagrass ranked lowest on 25 of 26 ET days. ‘Tifway’ ET rates ranged from 2.01 mm d^{-1} (Aug 16–17) to 7.41 mm d^{-1} (Jun 4 –5).

In year II, there was statistical significance for the “grass” effect ($p<0.05$) on 15 of 21 ET measurement days. Saltgrass ET ranked highest on 17 of 21 ET days, of which the saltgrass ET was statistically ($p<0.05$) greater than both paspalum and ‘Tifway’ on six days. Saltgrass ET ranged from 4.09 mm d^{-1} (Sept 1-2) to 8.69 mm d^{-1} (Sept 2–3). As in year I, the paspalum ET rates were generally intermediate between that of saltgrass and 'Tifway'. Paspalum ET rate was intermediate on 16 of 21 ET measurement days, was highest on three ET measurement days, and lowest on two days in year II. Paspalum ET ranged from 3.77 mm d^{-1} (Sept 1-2) to 8.12 mm d^{-1} (Jun 28-29) (Table 2). In year II, 'Tifway' ranked lowest numerically on 18 of 21 ET measurement days and had a significantly ($p<.05$) lower ET rate than both paspalum and saltgrass on eight days. 'Tifway' ET ranged from 3.67 mm d^{-1} (Sept 1-2) to 7.11 mm d^{-1} (Jun 27-28).

Consumptive Water Use

One objective of the study was to determine whether measurable differences in total consumptive use existed between species. In year I, the grass mean square for the total consumptive water use for 26 concurrent ET measurement days was significant ($p< 0.05$) (Table 1). There was also a significant difference ($p<0.05$) in consumptive water use for four of the five dry-down cycles (DDCs) in 2006 (Table 3).

Saltgrass CWU ranked highest in all cases and was significantly ($p<0.05$) greater than seashore paspalum and 'Tifway' bermudagrass in CWU in DDC3, DDC4, and DCC5 (Table 3). Paspalum had the second highest and 'Tifway' the lowest CWU use in each of the five DDCs during year I. The 'Tifway' CWU was significantly ($p<0.05$) lower in DDC1 and DDC2.

In year I, CWU values were 160.9 mm, 150.6 mm, and 142.0 mm for saltgrass A138, seashore paspalum, and 'Tifway' bermudagrass, respectively. These values represent the sum of all ETs for the 26 concurrent non-stress ET days in year I. As a percentage of the consumptive water use of saltgrass A138, seashore paspalum and 'Tifway' bermudagrass used 94% and 88%, respectively (Table 1).

In year II, consumptive water use was significant for seven of the eight DDCs in year II (Table 3). Saltgrass CWU ranked highest in seven of eight DDCs and was significantly different ($p<0.05$) from other grasses in four of eight cycles (DDC7, DDC8, DDC12, and DDC13). Paspalum CWU was intermediate relative to the other two grasses in all cycles and was significantly different from both grasses ($p<.001$) in DDC12 and DDC13 in year II. Bermudagrass consumptive water use was significantly ($p<.05$) lower than other grasses in five of the eight DDCs in year II.

In year II, the total consumptive water use summed over 21 days was also significant ($p<0.05$) with CWU at 137.9 mm, 130.2, and 120.8 mm for saltgrass, paspalum, and 'Tifway', respectively (Table 1). The findings were similar in year II as seashore paspalum used 94% and 'Tifway' bermudagrass used 88% as a percentage of saltgrass CWU (Table 1). The two year ET totals were 298.8, 280.8, and 262.8 mm for saltgrass, paspalum, and bermudagrass, respectively (Table 3).

DDCs 9, 10, and 11 lasted the fewest number of days for paspalum and 'Tifway' within a cycle. These mid-summer values occurred at a time when lysimeters were exposed to potential high solar radiation, low VPD, and intermittent swings of cloud cover/bright skies which could reduce leaf acclimation to direct solar radiation. This was noted as 'Tifway' wilted after just one day of exposure in DDC11 and pasaplum lasted only two to three days in DDC9 and DDC10. This was not related to ET_o over cycle periods.

Crop Coefficients (K_c)

Daily values:

K_cs were calculated by dividing actual grass evapotranspiration by reference evapotraspiration computed using the original AZMET equation from data collected by an onsite AZMET weather station. As expected by definiton, K_c values followed the same order as actual non-stress total water use in both years. K_c values were significantly ($p < 0.05$) different between species on 19 of 26 days in year I and 15 of 21 days in year II (Table 4). K_c values were largest in value at the beginning of a DDC, and were generally lower as self-imposed drought increased or became more severe.

Generally, the saltgrass K_c was highest, followed by seashore paspalum, then 'Tifway'. In year I, K_c values ranged from 0.55 to 1.31 for saltgrass, 0.54 to 1.03 for paspalum, and 0.52 to 0.97 for 'Tifway' bermudagrass (Table 4). The K_cs obtained in year I agree with those determined by Brown et al. (2001) for 'Tifway' bermudagrass grown in Tucson, AZ in a desert turf system. Brown et al. (2001) found that bermudagrass K_cs ranged from 0.76 in May to 0.83 in September, and acknowledged that the use of a constant K_c of 0.78 would be sufficient for estimating ET_a in summer. In this publication, Brown found that reference evapotranspiration differed between the AZMET and Penman-Monteith computation of ET_o in the summer months by as little as .01 in August to as much as 0.09 in May. In year II, K_c values ranged from 0.59 to 1.15 for saltgrass, 0.54 to 0.93 for paspalum, and 0.62 to 0.86 for 'Tifway' (Table 4).

<u>Cycle Basis:</u>

In addition, non-stress 'cycle' K_c values were developed by dividing cumulative ET_a by cumulative ET_o for the 'cycle' period when all lysimeters were present in the test (26 day total in year I, and 21 day total in year II). A combined analysis was first performed to measure the effects of grass, year, and grass x year interaction. The main effects of grass and year were highly significant ($p<0.0006$), although the grass x year interaction was not (Table 5). Non-stress 'cycle' K_c values were significant ($p<0.01$) in 11 of the 13 DDCs over both years (Table 6). Saltgrass K_cs were highest in rank in 12 of the 13 DDCs over the two-year study. Bermudagrass K_cs ranked lowest in all 13 'cycles'.

In year I, the saltgrass non-stress cycle K_c values were significantly higher than both of the other grasses in two of five DDCs (Table 6). Bermudagrass K_cs were significantly lower than saltgrass and paspalum K_cs in two DDCs during year I. K_cs ranged from 0.76 (DDC2) to 0.99 (DDC5) for saltgrass. Paspalum K_cs ranged from 0.75 (DDC2) to 0.92 (DDC3), and bermudagrass K_cs ranged from 0.70 (DDC2) to 0.87 (DDC3).

The following summer, saltgrass K_cs were significantly higher than those of both other grasses in four of the eight DDCs, and bermudagrass K_cs were lowest in five DDCs. Saltgrass K_cs ranged from 0.73 (DDC6) to 0.94 (DDC12), with paspalum K_cs ranging from 0.68 (DDC8) to 0.91 (DDC11). In year II, bermudagrass K_cs ranged from 0.64 (DDC8) to 0.81 (DDC12) (Table 6).

Year Basis:

Yearly K_c values for non-stressed turf were calculated by summing grass ET_a and respective reference ET_o values for all days when all lysimeters were present. From these summations, a single yearly K_c was calculated as: (Total ET_a/Total ET_o). This resulted in mean K_c values for year I and year II. These data were then used to perform an ANOVA for a calculated analysis, by year analysis, and analysis for the two-year sum.

In year I, K_cs averaged 0.89, 0.84, and 0.79 for saltgrass, paspalum, and 'Tifway' (Table 5). The same order was observed in year II, with the K_cs averaging 0.80, 0.75, and 0.70. K_cs calculated as the sum ET_a/sum ET_o when all lysimeters were present over both years of the study were 0.85, 0.79, and 0.74 for A138 saltgrass, 'Sea Isle I' paspalum, and 'Tifway' bermudagrass.

Section II.

Post-Stress Comparisons

Consumptive Water Use

There were statistically significant differences in average cycle consumptive water use rates (i.e., cumulative ET values) between 'Sea Isle 1' seashore paspalum, 'Tifway' bermudagrass, and saltgrass A138 in both years. First, a combined analysis was performed to determine the effects of grass, year, and grass x year interaction. Year and grass were both significant ($p<0.002$) and there was a significant year x grass interaction ($p<0.001$) (Table 7). The grass x year interaction although statistically significant, had little biological significance, as grasses remained similar in relative CWU values.

Paspalum had a CWU value closer to that of 'Tifway' in year II, than in year I, thus, resulting in a statistically significant interaction. Table 7 values indicate the average CWU before drought-induced wilt occurred for each grass.

In year I, the differences between CWU rates of grass species were statistically significant ($p < 0.0001$) for all five DDCs (Table 8). Saltgrass had a significantly ($p < 0.0001$) higher CWU than other grasses in all five DDCs in the first season. Saltgrass CWU ranged from a low of 58.61 mm over 14 days (DDC4) to a high of 88.48 mm over 11.75 days (DDC1). Paspalum had the second highest CWU in all DDCs in year I. Paspalum CWU ranged from 24.57 mm over 6 days (DDC4) to 47.70 mm over 6 days (DDC1). 'Tifway' had a significantly ($p < 0.0001$) lower CWU than both saltgrass and seashore paspalum in all cycles in year I. 'Tifway' CWU ranged from 18.60 mm over 5 days (DDC4) to a high of 29.85 mm over 9 days (DDC5).

Consumptive water use was significant ($p<0.02$) for all eight DDCs in the second year (Table 8). Saltgrass had significantly ($p<.002$) higher CWU than both remaining grasses in all eight DDCs, ranging from 45.99 mm over 8 days (DDC7) to 75.09 mm over 10.75 days (DDC10). Paspalum CWU ranged from 19.08 mm over 2.75 days (DDC11) to 29.47 mm over 5.75 days (DDC6). 'Tifway' CWU was significantly ($p<.0001$) lower than paspalum and saltgrass in two DDCs, with CWU ranging from 6.02 mm on one day (DDC11) to 24.76 mm over 4.75 days (DDC6) (Table 8).

In year I, averaged over all plots and DDCs, saltgrass remained in the study for a total of 67.75 days (over 5 DDC). The mean consumptive water use over this time-period was 361.4 mm (Table 9). Paspalum was in the test for a total of 37 days in the first summer, with a total water-use of 190.9 mm. ‘Tifway’ was in the experiment for a total of 28 days with a mean consumptive-use of 130.5 mm (Table 9).

The same treatment response order was observed again in year II. Saltgrass was in the test for 81.83 days (over 8 cycles) with a consumptive-use of 473.0 mm when summed over all DDC test days. Paspalum was in the test 32.72 days using 196.8 mm of water over that time-period. Finally, ‘Tifway’ remained in the test for a total of 24.25 days in year II, with a consumptive water use of 136.2 mm.

Crop Coefficients

K_cs were developed by dividing the cumulative ET_a by cumulative ET_o for the time period that an individual lysimeter was present in the test before being removed due to visible drought stress. This allowed the examination of mean K_cs from initial well-watered conditions until leaf wilting was observed.

The grass x year interaction was statistically significant ($p<0.0166$) (Table 10). K_cs by year averaged over all grasses was 0.77 for year I, and 0.72 in year II. Thus, turf water use was slightly nearer to the evaporative demand in year I than year II. This could be due to the lysimeters becoming pot-bound in the second year, decreasing root development.

Based on cycle totals, K_c values were significant ($p<0.03$) in three of five dry down cycles in year I (Table 11). K_c values averaged 0.79, 0.76, and 0.76 for ‘Sea Isle I’ paspalum, bermudagrass, and saltgrass, respectively (Table 10). In year I, mean K_cs ranged from 0.68 (DDC) to 0.84 (DDC5) for ‘Sea Isle I’ paspalum, 0.66 (DDC4) to 0.84

(DDC3) for bermudagrass, and 0.70 (DDC4) to 0.89 (DDC3) for saltgrass (Table 11). There was not a specific trend in numerical rank with regard to K_c values in year I (Table 11).

K_c values were significant (*p<0.03*) in three of the eight dry down cycles in the second summer (Table 11). The mean K_cs were lower in the second year, averaging 0.74, 0.74, and 0.70 for paspalum, saltgrass, and bermudagrass, respectively (Table 10). Bermudagrass K_c values were lowest in rank in six of the eight cycles in year II. Over the two-year study, saltgrass K_c values were highest in rank in seven cases, with paspalum being intermediate relative to saltgrass and bermudagrass in nine cycles, and bermudagrass demonstrating the lowest K_c value in nine of thirteen DDCs. Mean K_c values for paspalum ranged from 0.65 (DDC6) to 0.84 (DDC11), 0.63 (DDC8) to 0.78 (DDC12) for bermudagrass, and 0.63 (DDC6) to 0.86 (DDC11) for saltgrass (Table11).

The 'Tifway' K_c values found in our study were higher than the bermudagrass K_cs reported by Garrot and Mancino (1994). They reported a K_c of 0.64, 0.60, and 0.57 for 'Texturf-10', 'Tifgreen' and 'Midiron' bermudagrasses over a three-year study. However, their research was conducted in a field study with turf grown on a loam soil, and consumptive water use was determined using the gravimetric method. Their study was also flood irrigated and would allow for considerably higher soil moisture contents following an irrigation event, as the calcined clay used in our study drained very rapidly. They also reported K_c values as low as 0.10 which suggests they allowed turf to wilt to a much greater extent.

Crop Coefficients at the Point of Stress

K_c values were examined for all treatments at the point of visible drought-stress (the day before they were removed from the field). First, a combined analysis was performed to determine the effects of grass, year, and grass x year interaction. Year and grass were both significant ($p<0.009$) and there was a significant year x grass interaction ($p<0.004$) (Table 12). Paspalum had the highest final K_c in both years, but was closer to that of bermudagrass in year II, causing a grass x year interaction. Saltgrass had the lowest final K_c in both years.

In year I, the final K_c was significantly different among grasses in all five DDCs (Table 13). The final K_c value for paspalum ranked highest in all cases, and was significantly ($p <0.03$) greater than saltgrass and 'Tifway' in three of the five cycles. The final K_c for saltgrass was lowest numerically in four DDCs, and was significantly different from other grasses in those DDCs. 'Tifway' was generally intermediate in rank and stood alone in DDC1 and DDC2. In year I, the average final K_c values were 0.77, 0.70, and 0.62 for 'Sea Isle I' paspalum, 'Tifway' bermudagrass, and saltgrass, respectively (Table 12).

In year II, the final K_c value was significant in two of the eight DDCs (Table 13). The same treatment response was observed in the second year with paspalum ranking highest numerically in five of the eight DDCs. The final K_c value for 'Tifway' statistically was equal to that of paspalum in all eight cases and equal to that of saltgrass in six of the eight cases. Saltgrass ranked lowest in five cycles and was significantly lower than both other grasses in one cycle (DDC10) and significantly lower than

'Tifway' in one cycle (DDC7). In year II, the final K_c values averaged, 0.67, 0.66, and 0.62 for paspalum, bermudagrass, and saltgrass, respectively (Table 12).

The difference between the non-stress K_c and the final K_c was computed based on treatment means in order to determine to what extent the realized crop coefficient decreased from non-limiting soil moisture conditions until drought stress was observed. The results indicated that saltgrass had the greatest decrease in K_c from the beginning of a DDC until stress was observed. Averaged across all 13 DDCs, saltgrass decreased 0.23, followed by pasaplum which decreased 0.09, and 'Tifway' which demonstrated only a 0.06 reduction (data not shown).

Days before Visible Drought Stress

Another objective of this study was to determine the amount of time these grasses could maintain asymptomatic leaf turgor following a single irrigation event prior to showing visible signs of water stress. The combined two-year analysis showed a significant main effect for "grass" and for the interaction of grass x year. The interaction was a result of saltgrass having relatively more days in ET phase (compared to other grasses) in year II, than in year I. Treatment results, order, and ranking were otherwise unchanged from year to year.

The results demonstrated a significant difference ($p < 0.001$) in the number of days grasses remained in a DDC prior to being removed for visible drought stress for both years (Table 14). As acknowledged by Pessarakli et al. (2001), we found that saltgrass was more tolerant to drought stress than bermudagrass. ‘Tifway’ was the least drought-tolerant of all three grasses in both years.

In year I there was a significant ($p < 0.0001$) difference in the number of days the grasses remained in test before exhibiting drought induced wilt stress (Table 14). This was true for all five DDC events (Table 15). Saltgrass remained in all dry down cycles the greatest number of days, followed by paspalum, and ‘Tifway’. Saltgrass transpired on average, 13.6 d before showing critical drought stress wilt. Seashore paspalum was able to go 7.4 d before wilt was observed, whereas ‘Tifway’ bermudagrass averaged 5.6 d before requiring irrigation in year I (Table 15).

In year II there was also a significant ($p<0.001$) difference in the number of days the three grasses remained in the test before drought stress became apparent (Table 15). The same order for treatment responses occurred in the second year. However, the number of days between irrigations was fewer for all grasses in the second year. Saltgrass transpired without wilt stress on average at 10.2 d intervals, while paspalum lasted on average 4.1 d without wilt stress, and ‘Tifway’ remained in dry down cycles an average of 3.0 d (Table 15). This equated to a 25, 45, and 46% reduction in the number of days the grasses remained in a DDC from year I to year II for saltgrass, paspalum, and ‘Tifway’, respectively.

Fraction of Available Water at Wilting Point

There were statistically significant (*p<0.007*) differences in the fraction of available water (FAW) within the lysimeter between saltgrass, seashore paspalum, and 'Tifway' at the time of removal for visible drought stress, with the main effects of year and grass being statistically significant. The grass x year interaction was also statistically significant (Table 16). However, the grass x year interaction was not biologically significant according to rank and value as all treatments exhibited a higher FAW on the day of removal in the second year, and the order of removal remained unchanged from the first year of the study (Table 16).

Saltgrass had a significantly (*p<0.0001*) lower mean FAW on the day of removal due to drought stress than both paspalum and 'Tifway' in all DDCs of year I (Table 17). Thus, we found that saltgrass "leaf curling/wilting" occurred at a significantly lower fraction of available water than that of both paspalum and 'Tifway'. 'Tifway' had a significantly (*p<.0001*) higher mean FAW than both grasses on the day it was removed for drought stress in three DDCs in the first year and was highest numerically in rank in all cases (Table 17). In the first year, the FAW on the day of removal for 'Tifway' ranged from 0.64 (DDC2) to 0.81 (DDC1). FAW at the time of removal of paspalum ranged from 0.56 (DDC2) to 0.68 (DDC1, DDC3, DDC4). In year I, the FAW at removal of saltgrass was much lower ranging from 0.33 (DDC2, DDC3) to 0.35 (DDC1, DDC5). The mean FAW upon removal averaged over all DDCs was 0.34, 0.66, and 0.74 for saltgrass, paspalum, and 'Tifway', respectively (Table 16).

In year II, the same response pattern was observed for saltgrass. Saltgrass had significantly ($p<0.007$) lower mean FAWs than both paspalum and 'Tifway' upon removal for visible drought stress in all eight DDCs (Table 17). There was not a statistical difference between paspalum and 'Tifway' FAWs at removal, yet 'Tifway' was highest in rank for FAW in six of the eight cycles. The mean FAWs upon removal averaged over all cycles increased from year I to year II for all grasses as cycles decreased in the number of days (as previously discussed) (Table 15). The FAWs at removal for 'Tifway' ranged from 0.74 (DDC6) to 0.88 (DDC11) (Table 17). Paspalum FAWs upon removal ranged from 0.73 (DDC6, DDC12) to 0.85 (DDC10). Finally, the saltgrass was removed in year II with FAWs ranging from 0.34 (DDC10) to 0.59 (DDC9). The average FAWs were 0.48, 0.79, and 0.80 for saltgrass, paspalum, and 'Tifway', respectively (Table 16).

Over both years of the study, the average FAWs at removal were 0.77, 0.72, and 0.41, for bermuda, paspalum, and saltgrass, respectively. Over the two-year study, saltgrass wilted at a lower FAW and thus remained unstressed under drier soil conditions for longer periods than 'Tifway' bermudagrass and paspalum. Following the conclusion of the test, a destructive sampling of the lysimeters was performed. It was concluded through visual observation that both saltgrass and bermudagrass produced a similar rooting depth, and apparent root mass, with both species rooting in a conical profile to the bottom of the lysimeter root zone. In every case, it was observed that paspalum had a considerably shallower root-zone. Thus, paspalum was still capable of maintaining stress-free turf for a greater number of days than 'Tifway' following a single irrigation event even though the FAW at wilting was similar for these two grasses.

Stress-Degree Day

The stress-degree day parameter (SDD) was significant ($p<0.008$) in every DDC of year I (DDC1-5). Saltgrass had a significantly ($p<0.008$) greater mean SDD value than both other grasses in all DDCs in year I, ranging from a low of 15.37 °C (DDC1) to a high of 83.42 °C (DDC5) (Table 18). In year I, the SDD parameter for saltgrass averaged 43.39 °C when it was removed from the test due to visible drought stress (Table 18). The SDD parameter was not different between paspalum and 'Tifway' in year 1. Paspalum ranged from 6.31 °C (DDC2) to 34.30 °C (DDC5) upon removal, and that of 'Tifway' ranged from 1.45 °C (DDC1) to 31.98 °C (DDC5). Paspalum and 'Tifway' SDD averaged 19.14 and 15.60 °C at removal, respectively (Table 18).

In year II, the SDD parameter was significant ($p<0.05$). Saltgrass had the highest significant SDD value in seven of eight DDCs. Paspalum SDD was significantly ($p<0.0003$) higher than that of 'Tifway' in DDC11 (Table 18). In all other cases, SDD for these two grasses was not statistically different. Saltgrass SDD ranged from 8.17 °C (DDC9) to 71.91 °C (DDC6), paspalum ranged from 5.73 °C (DDC10) to 41.67 °C (DDC6), and 'Tifway' from a low of 4.03 °C (DDC8) to 30.94 °C (DDC6). The mean SDD in year II was 41.67, 19.32, and 13.87 °C for saltgrass, paspalum, and 'Tifway', respectively (Table 18).

Critical Point Model

There was a significant statistical (*$p<0.02$*) difference in the critical-point model (CPM) in three of five DDCs in year one (Table 19). In year I, saltgrass ranked numerically highest in all DDCs. Paspalum ranked second highest in two cycles, and 'Tifway' ranked second highest in two DDCs. The mean saltgrass CPM ranged from 3.56 °C (DDC1) to 13.48 °C (DDC5). Paspalum CPM ranged from -0.66 °C (DDC2) to 9.73 °C (DDC5), and 'Tifway' CPM ranged from -0.03 °C (DDC1) to 10.96 °C (DDC5) (Table 19).

In year II, the treatment main effect was significant for CPM in four of the eight DDC events. The critical-point model was significant (*$p<0.05$*) in four of eight DDCs. Saltgrass ranked highest numerically in four DDC, 'Tifway' ranked highest in three DDC, and paspalum ranked highest in one DDC. Saltgrass CPM ranged from 1.08 °C (DDC9) to 12.66 °C (DDC11). Paspalum ranged from 3.95 °C (DDC8) to 10.55 (DDC7) and 'Tifway' CPM ranged from 2.45 (DDC8) to 11.28 (DDC13) (Table 19).

The CPM model results show no trends in the absolute difference in (T_c-T_a) values at the point of visible turfgrass wilt stress, as saltgrass occasionally showed a lower CPM value than the other two grasses at its removal point (DDC9,DDC13). Note again that saltgrass remained in the test a greater number of non-stress transpirational days than the other two turfs. CPM values were more variable in terms of elevated temperature occurring within a cycle. In some cases, the CPM was higher on days before the day of actual removal of the lysimeter (data not shown). Thus, SDD was the better of the two models for simple assessment of (T_c-T_a).

Growth Characteristics

Analysis of variance for shoot biomass as verdure showed no significant statistical difference among these three turfgrasses following a destructive-sampling at the conclusion of the test (Table 20). Paspalum ranked numerically greatest with 26.32g, followed by 'Tifway' at 23.30g, and saltgrass with 20.21g of shoot biomass from the 506-cm2 lysimeter area. Therefore, above ground biomass was apparently the same for all three grasses. Analysis of variance for total estimated shoot counts were found to be statistically significant ($p<0.0002$). The leaf area indices (LAI) averaged 7.25 for paspalum, 6.52 for 'Tifway', and 2.71 for saltgrass. Although saltgrass had the greatest average leaf area per shoot (21.19 cm^2), it had the lowest shoot density at the conclusion of the test, and thus the lowest leaf area and LAI values.

CHAPTER 5

CONCLUSIONS

Non-Stress Comparisons

Section I.

Consumptive Water Use

This study demonstrated that saltgrass clone A138 and 'Sea Isle I' seashore paspalum did not use less water than 'Tifway' bermudagrass under non-limiting soil moisture conditions, based on the absence of leaf wilting. For all instances, grass treatment effects were determined to be significant on 34 of 47 comparative ET measurement days. In general, saltgrass used the greatest amount of water as its mean ET_a and CWU were statistically different from 'Sea Isle I' paspalum and 'Tifway' bermudagrass. 'Tifway' had the lowest ET and CWU under non-stress conditions

In year I, CWU values were 160.9 mm, 150.6 mm, and 142.0 mm for saltgrass A138, seashore paspalum, and 'Tifway' bermudagrass, respectively over 26 concurrent ET measurement days under stress free periods. In year II, the total consumptive water use summed over 21 days was 137.9 mm, 130.2, and 120.8 mm for saltgrass, paspalum, and 'Tifway', respectively

Crop Coefficients

Daily Values:

By convention, K_c values followed the order of actual turf water use. As would be expected, K_c values were slightly larger in value at the beginning of a dry down cycle, and were generally lower as self-imposed drought increased or became more severe.

The mean K_cs for non-stressed turfs in year I were 0.90, 0.83, and 0.82, for saltgrass, seashore paspalum, and 'Tifway', respectively. The same order of mean K_c values was observed in year II averaging 0.81, 0.76, and 0.71, for saltgrass, paspalum, and 'Tifway', respectively. K_c values averaged over both years of the study were 0.86 for saltgrass, 0.80 for paspalum, and 0.76 for bermudagrass.

Year Basis:

K_c values under non-stress conditions in year I averaged 0.89, 0.84, and 0.79 for saltgrass, paspalum, and 'Tifway', respectively. In year II, the same order was observed with respective mean K_c values of 0.79, 0.75, and 0.70, respectively.

Post-Stress ET Comparisons

Section II.

Consumptive Water Use

Saltgrass demonstrated a significantly greater CWU than both ‘Tifway’ and paspalum in all 13 cycles over the two-year study. This is due to saltgrass being subjected to two to three times as many ET measurements, as saltgrass was able use more plant-available water and remain in the test for longer periods before drought stress was expressed through leaf wilting.

Crop Coefficients

In year I, ‘Sea Isle I’ had the greatest K_c value of 0.79. Saltgrass and ‘Tifway’ had the same average K_c value of 0.76. In the second year, saltgrass and paspalum shared the highest mean K_c value at 0.74, followed by ‘Tifway’ which averaged 0.69.

Crop Coefficients at the Point of Stress

In year I, the final K_c value prior to being removed due to drought-stress for paspalum averaged 0.77, followed by ‘Tifway’ and saltgrass averaging, 0.70, and 0.62, respectively. The same treatment response was observed in year II, with the final K_c values averaging, 0.67, 0.66, and 0.62 for paspalum, bermudagrass, and saltgrass, respectively.

Days before Visible Drought Stress

Saltgrass remained in the test the greatest number of days before drought stress was expressed through moderate leaf wilting. Over the two-year test, saltgrass transpired on average 11.9 d before turf stress was observed. 'Sea Isle I' seashore paspalum was intermediate and transpired on average, 5.8 days before leaf wilting was expressed. 'Tifway' bermudagrass wilted most rapidly, remaining in the test an average of 4 d before leaf wilting was observed.

Fraction of Available Water

The results demonstrated that saltgrass wilted under considerably drier soil moisture conditions. In both summers, paspalum was intermediate in the FAW used prior to wilt. 'Tifway' wilted most rapidly, even at relatively high soil moisture contents. The mean FAWs at the time of wilting point averaged over both years were 0.41, 0.72, and 0.77 for saltgrass, paspalum, and 'Tifway', respectively.

Stress-Degree Day

The use of infrared thermometry indicated that saltgrass tolerated greater elevated leaf temperatures than both paspalum and bermudagrass. 'Tifway' developed high leaf temperatures the most rapidly but wilted at lower canopy minus air temperatures than both saltgrass and paspalum. The mean SDD value in year I was 43.39, 19.14, 15.60 °C for saltgrass, paspalum, and bermudagrass, respectively. In year II, the mean SDD value was 41.67, 19.32, and 13.87 °C for saltgrass, paspalum, and 'Tifway', respectively.

Critical Point Model

Our findings showed that there was no valid trend regarding the absolute ($T_c - T_a$) value at the time of wilting point across the two-year study. The critical point was not an effective indicator of plant stress as canopy minus air temperature varied greatly due to dynamic weather fluctuations. This is likely due to variations in atmospheric parameters such as the amount of incoming solar radiation due to varying cloud cover across ET measurement days, as well as variations in temperature and humidity (VPD).

Growth Characteristics

Destructive sampling results indicated differences in growth characteristics between the three grasses. Sampling and subsequent analysis showed there was no difference in shoot biomass. Root zone profile extraction observations indicated considerable differences in rooting depth and apparent root mass. Saltgrass and 'Tifway' had similar apparent root mass and both displayed a conical taper of roots towards the bottom of the lysimeter. Paspalum had a considerably shallower root base than saltgrass and 'Tifway'. This is important as rooting depth has been proven to be an important trait for grass drought avoidance (Carrow, 1996; Hays et al., 1991; Huang et al., 1997; Sheffer et al., 1987; White, et al., 1993). As expected, grasses with deep root systems may have an advantage, as they are capable of absorbing water from deeper in the soil profile (Huang, 1999).

Shoot counts also revealed that paspalum and 'Tifway' had a significantly higher number of shoots than saltgrass and thus a significantly higher total estimated leaf area.

Based on sampling individual shoots, saltgrass had the greatest leaf area, but the fewest number of shoots, and thus the lowest total estimated leaf area. This is important as turf canopies possessing high shoot density and dense foliage may increase resistance to the vertical movement of water vapor within the canopy and reduce turbulent mixing with the bulk air from above, increasing the water vapor content within the canopy, and thus reducing VPD and ET (Ebdon and Petrovic, 1998).

Table 1: Combined year analysis for non-stress CWU[1] comparisons. University of Arizona.

	Pr > F		Mean CWU and Duncan's MRT Value[3]	% of Saltgrass CWU
Year[2] (averaged over grass)	0.0002	Year I	151.2 A (26d)	
		Year II	129.6 B (21d)	
Grass (averaged over years)	0.0001	Saltgrass	149.3 A	100%
		Paspalum	140.4 B	94%
		Tifway	131.4 C	88%
			Year I	
Year x Grass	0.64	Saltgrass	160.9 A	100%
		Paspalum	150.6 B	94%
		Tifway	142.0 C	88%
			Year II	
		Saltgrass	137.9 A	100%
		Paspalum	130.2 B	94%
		Tifway	120.8 C	88%

[1] CWU = ET Total (mm) summed for all non-stress cycles.

[2] Year I = 5 Dry-down cycles from June 2 - September 17, 2006. Year II = 8 Dry-down cycles from May 1 - September 14, 2007.

[3] Duncan's New Multiple Range Test. Treatments within an analysis with the same letter(s) are not statistically different. P=0.05.

Table 2. Mean daily ET rate (mm d^{-1})[1] of three grasses under non-stress conditions. Summer 2006 and 2007. University of Arizona.

Date	ET day[2]	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[3]	Significance level[4]
6/2-6/3	d1	6.10 a[5]	5.50 b	6.05 a	5.88	xx
6/3-6/4	d2	7.68 a	7.01 b	7.63 a	7.44	x
6/4-6/5	d3	8.39 a	7.41 b	8.81 a	8.20	xx
6/5-6/6	d4	6.96 b	6.29 c	7.48 a	6.91	xxx
6/16-6/17	d5	5.83 a	5.11 b	5.26 ab	5.40	NS
6/17-6/18	d6	7.41 a	6.96 b	7.18 ab	7.18	NS
6/18-6/19	d7	7.50 ab	7.16 b	7.77a	7.48	NS
6/19-6/20	d8	7.38 b	7.03 c	7.95 a	7.45	xx
6/20-6/21	d9	6.99 b	6.64 b	7.43 a	7.02	xx
7/6-7/7	d10	5.60 b	5.38 c	5.87 a	5.62	xxx
7/7-7/8	d11	3.69 a	3.62 a	3.77 a	3.69	NS
7/8-7/9	d12	7.36 a	6.66 a	7.03 a	7.02	NS
7/9-7/10	d13	7.45 b	7.16 c	7.82 a	7.48	xxx
7/10-7/11	d14	6.61 b	6.37 b	7.48 a	6.82	xx
8/15-8/16	d15	5.68 a	5.65 a	6.00 a	5.78	NS
8/16-8/17	d16	2.06 b	2.01 b	2.18 a	2.08	xx
8/17-8/18	d17	5.13 a	5.11 a	5.31 a	5.18	NS
8/18-8/19	d18	6.00 b	5.83 b	6.91 a	6.25	xxx
8/19-8/20	d19	5.21 b	5.28 b	5.80 a	5.43	x
8/31-9/1	d20	5.70 b	5.48 b	6.10 a	5.76	x
9/1-9/2	d21	6.59 ab	6.17 b	6.96 a	6.57	x
9/2-9/3	d22	5.16 b	4.76 b	5.83 a	5.25	xx
9/3-9/4	d23	3.65 b	3.53 b	4.89 a	4.02	xx
9/4-9/5	d24	2.91 b	2.64 c	3.41 a	2.99	xxx
9/5-9/6	d25	3.78 b	3.58 b	4.48 a	4.06	xxx
9/6-9/8	d26	3.77 b	3.68 b	5.11 a	4.19	xxx
5/1-5/2	d27	5.33 ab	4.76 b	5.46 a	5.18	NS
5/2-5/3	d28	5.97 a	5.60 a	6.05 a	5.87	NS
5/3-5/4	d29	5.97 a	5.73 a	6.52 a	6.07	NS
5/4-5/5	d30	4.74 a	5.43 a	5.13 a	5.10	NS
5/15-5/16	d31	6.57 b	6.15 c	6.91 a	6.54	xxx
5/16-5/17	d32	5.21 ab	4.87 b	5.53 a	5.20	x
5/17-5/18	d33	5.48 b	5.80 ab	6.54 a	5.94	x
5/30-5/31	d34	6.82 ab	6.42 b	7.16 a	6.80	x
5/31-6/1	d35	6.20 ab	5.70 b	6.62 a	6.17	x
6/1-6/2	d36	5.78 b	5.60 b	6.66 a	6.01	x
6/14-6/15	d37	6.94 a	6.29 b	6.99 a	6.74	xx
6/15-6/16	d38	7.55 a	6.47 b	7.82 a	7.28	x
6/27-6/28	d39	8.05 a	7.11 b	7.85 a	7.67	x
6/28-6/29	d40	8.12 a	7.06 b	8.49 a	7.89	x
7/18-7/19	d41	7.41 a	6.02 b	7.24 a	6.89	xxx
8/13-8/14	d42	6.32 b	5.95 c	6.76 a	6.34	xxx
8/14-8/15	d43	5.66 b	5.14 c	6.03 a	5.61	xxx
9/1-9/2	d44	3.77 b	3.67 b	4.09 a	3.84	x
9/2-9/3	d45	6.99 a	6.49 a	8.69 a	7.39	NS
9/3-9/4	d46	6.15 a	5.58 a	5.31 a	5.68	NS
9/4-9/5	d47	5.16 b	4.94 b	6.07 a	5.39	x

[1] Water use in mm d^{-1}. Values are the mean of four replications.

[2] d1-d47 = (n) day of measurement. Days 1-26 = Year I, 2006. Days 27-47 = Year II, 2007.

[3] Test mean = Mean of all treatments on each day of measurement.

[4] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

[5] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05

Table 3. Mean consumptive-water use (CWU)[1] totals of three grasses under non-stress conditions. Summer 2006 and 2007. University of Arizona.

Year I Cycles	Days[2]	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[3]	Significance level[4]
DDC1	4d	29.13 a[5]	26.22 b	29.97 a	28.44	xx
DDC2	5d	35.10 a	32.91 b	35.59 a	34.53	x
DDC3	5d	30.72 ab	29.19 b	31.98 a	30.63	NS
DDC4	5d	24.08 b	23.88 b	26.20 a	24.72	xx
DDC5	7d	31.57 b	29.85 b	37.13 a	32.85	xxx
Yearly CWU		150.59 b	142.03 c	160.87 a	151.17	xxx
Year II Cycles						
DDC6	4d	22.02 a	21.52 a	23.15 a	22.23	NS
DDC7	3d	17.25 b	16.81 b	18.98 a	17.68	xx
DDC8	3d	18.78 b	17.72 b	20.44 a	18.98	xx
DDC9	2d	14.49 a	12.76 b	14.81 a	14.02	xx
DDC10	2d	16.17 a	14.17 b	16.34 a	15.56	xx
DDC11	1d	7.41 a	6.02 b	7.24 a	6.89	xxx
DDC12	2d	11.98 b	11.09 c	12.80 a	11.96	xxx
DDC13	4d	22.06 b	20.68 c	24.16 a	22.30	xx
Yearly CWU		130.16 b	120.78 c	137.92 a	129.62	xxx
Two Year Total		280.75	262.81	298.79	280.79	-

[1] CWU = ET (mm) summed over total number of days in cycle. Values are the mean of four replications.

[2] Days = mean number of days before first lysimeter was removed based on visible drought-stress.

[3] Test mean = Mean of all treatments for each dry-down cycle.

[4] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

[5] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05.

Table 4. Mean daily crop coefficient (Kc)[1] of three grasses under non-stress conditions. Summer 2006 and 2007. University of Arizona.

Year I	ET day[2]	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[3]	Significance level[4]
6/2-6/3	d1	0.99 a[5]	0.90 b	0.99 a	0.96	xx
6/3-6/4	d2	0.82 a	0.75 b	0.81 a	0.79	x
6/4-6/5	d3	0.85 a	0.75 b	0.89 a	0.83	xx
6/5-6/6	d4	0.76 b	0.69 c	0.82 a	0.76	xxx
6/16-6/17	d5	0.61 a	0.53 b	0.55 ab	0.56	NS
6/17-6/18	d6	0.79 a	0.74 b	0.76 ab	0.76	NS
6/18-6/19	d7	0.78 ab	0.74 b	0.81 a	0.78	NS
6/19-6/20	d8	0.81 b	0.77 c	0.88 a	0.82	xx
6/20-6/21	d9	0.77 b	0.74 b	0.82 a	0.78	xx
7/6-7/7	d10	0.85 b	0.92 c	1.00 a	0.96	xxx
7/7-7/8	d11	0.60 ab	0.54 b	0.63 a	0.59	NS
7/8-7/9	d12	0.89 a	0.84 a	0.89a	0.88	NS
7/9-7/10	d13	0.90 b	0.87 c	0.95 a	0.91	xxx
7/10-7/11	d14	0.79 b	0.76 b	0.89 a	0.81	xx
8/15-8/16	d15	0.95 a	0.95 a	1.01 a	0.97	NS
8/16-8/17	d16	0.78 b	0.76 b	0.83 a	0.79	xx
8/17-8/18	d17	0.89 a	0.88 a	0.92 a	0.90	NS
8/18-8/19	d18	0.87 b	0.85 b	1.00 a	0.91	xx
8/19-8/20	d19	0.77 b	0.78 b	0.86 a	0.81	x
8/31-9/1	d20	0.89 b	0.86 b	0.95 a	0.90	x
9/1-9/2	d21	1.03 ab	0.97 b	1.09 a	1.03	x
9/2-9/3	d22	0.87 b	0.81 b	0.99 a	0.89	xx
9/3-9/4	d23	0.98 b	0.95 b	1.31 a	1.08	xx
9/4-9/5	d24	0.87 b	0.79 c	1.02 a	0.90	xxx
9/5-9/6	d25	0.79 b	0.75 b	1.01 a	0.85	xxx
9/6-9/8	d26	0.54 b	0.52 b	0.73 a	0.60	xxx
5/1-5/2	d27	0.84 ab	0.75 b	0.85 a	0.81	NS
5/2-5/3	d28	0.76 a	0.72 a	0.77 a	0.75	NS
5/3-5/4	d29	0.70 a	0.67 a	0.77 a	0.71	NS
5/4-5/5	d30	0.54 a	0.62 a	0.59 a	0.58	NS
5/15-5/16	d31	0.77 b	0.72 c	0.81 a	0.77	xxx
5/16-5/17	d32	0.83 ab	0.77 b	0.88 a	0.83	x
5/17-5/18	d33	0.66 b	0.71 ab	0.79 a	0.72	x
5/30-5/31	d34	0.68 ab	0.64 b	0.72 a	0.68	x
5/31-6/1	d35	0.74 ab	0.67 b	0.78 a	0.73	xx
6/1-6/2	d36	0.64 b	0.62 b	0.74 a	0.67	x
6/14-6/15	d37	0.73 a	0.66 b	0.74 a	0.71	xx
6/15-6/16	d38	0.75 a	0.64 b	0.77 a	0.72	x
6/27-6/28	d39	0.78 a	0.69 b	0.76 a	0.74	x
6/28-6/29	d40	0.81 a	0.71 b	0.85 a	0.79	xx
7/18-7/19	d41	0.91 a	0.74 b	0.89 a	0.85	xxx
8/13-8/14	d42	0.86 b	0.81 c	0.92 a	0.86	xxx
8/14-8/15	d43	0.91 b	0.82 c	0.97 a	0.90	xxx
9/1-9/2	d44	0.64 b	0.62 b	0.70 a	0.65	x
9/2-9/3	d45	0.93 a	0.86 a	1.15 a	0.98	NS
9/3-9/4	d46	0.77 a	0.70 a	0.67 a	0.71	NS
9/4-9/5	d47	0.72 b	0.69 b	0.85 a	0.75	x

[1] Kc = actual ET/reference ET. Values are the mean of four replications.

[2] d1-d47 = (n) day of measurement. Days 1-26 = Year I, 2006. Days 27-47 = Year II, 2007.

[3] Test mean = Mean of all treatments on each day of measurement.

[4] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

[5] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05

Table 5: Combined year analysis for non-stress Kc[1] comparisons. University of Arizona.

	Pr > F		Mean Kc and Duncan's MRT Value[3]
Year[2] (averaged over grass)	0.0006	Year I	0.84 A
		Year II	0.75 B
Grass (averaged over year)	<.0001	Saltgrass	0.85 A
		Paspalum	0.79 B
		Tifway	0.74 C
			Year I
Year x Grass	0.7369	Saltgrass	0.89 A
		Paspalum	0.84 B
		Tifway	0.79 C
			Year II
		Saltgrass	0.80 A
		Paspalum	0.75 B
		Tifway	0.70 C

[1]Kc = [Total Grass ET/Total Reference ET per cycle] summed for cycles 1-13. Twelve values per year, twenty-four values for two years.
[2]Year I = 5 Dry-down cycles from June 2 - September 17, 2006. Year II = 8 dry down cycles from May 1 - September 14, 2007.
[3]Duncan's New Multiple Range Test. Treatments within an analysis with the same letter(s) are not statistically different. P=0.05.

Table 6. Mean 'cycle' crop coefficient (K_c)[1] of three grasses under non-stress conditions. Summer 2006 and 2007. University of Arizona.

Year I Cycles	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[2]	Significance level[3]
DDC1	0.84 a[3]	0.76 b	0.87 a	0.82	xx
DDC2	0.75 a	0.70 b	0.76 a	0.74	x
DDC3	0.92 ab	0.87 b	0.95 a	0.91	NS
DDC4	0.86 b	0.85 b	0.94 a	0.88	xx
DDC5	0.84 b	0.80 b	0.99 a	0.88	xxx
Year II Cycles					
DDC6	0.70 a	0.68 a	0.73 a	0.71	NS
DDC7	0.75 b	0.73 b	0.82 a	0.77	xx
DDC8	0.68 b	0.64 b	0.74 a	0.69	xx
DDC9	0.74 a	0.65 b	0.75 a	0.71	xx
DDC10	0.79 a	0.70 b	0.80 a	0.76	xx
DDC11	0.91 a	0.74 b	0.89 a	0.85	xxx
DDC12	0.88 b	0.81 c	0.94 a	0.88	xxx
DDC13	0.77 b	0.72 c	0.85 a	0.78	xx

[1] 'Cycle' K_c developed by dividing cumulative mean ET_a by cumulative ET_o for the 'cycle' period when all lysimeters were present in the test.

[2] DDC = dry down cycles 1-13 during non-stress conditions. DDC1-DDC5 = Year I, 2006. DDC6-DDC13 = Year II, 2007.

[3] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05

[4] Test mean = Mean of all treatments on each day of measurement.

[5] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

Table 7: Combined year analysis for stress CWU[1] comparisons based on cycle averages. University of Arizona.

	Pr > F		Mean ET and Duncan's MRT Value[3]	% of Saltgrass CWU
Year[2] (averaged over grass)	0.0025	Year I	45.52 A	
		Year II	33.58 B	
Grass (averaged over year)	<.0001	Saltgrass	65.7 A	100%
		Paspalum	31.3 B	48%
		Tifway	21.6 C	33%
			Year I	
Year x Grass	0.0157	Saltgrass	72.3 A	100%
		Paspalum	38.2 B	53%
		Tifway	26.1 C	36%
			Year II	
		Saltgrass	59.1 A	100%
		Paspalum	24.6 B	42%
		Tifway	17.0 C	29%

[1] CWU = ET Total (mm) summed on an individual lysimeter basis until being removed for visible drought stress.

[2] Year I = 5 Dry-down cycles from June 2 - September 17, 2006. Year II = 8 Dry-down cycles from May 1 - September 14, 2007.

[3]Duncan's New Multiple Range Test. Treatments within an analysis with the same letter(s) are not statistically different. P=0.05.

Table 8. Mean consumptive-water use (CWU)[1] of three grasses until visible drought-stress was observed. Summer 2006 and 2007. University of Arizona.

Year I Cycles	Sea Isle I Paspalum	Days[2]	Tifway Bermuda	Days	A138 Saltgrass	Days	Test mean[3]	Significance level[4]
DDC1	47.70 b[5]	6.00	26.22 c	3.00	88.48 a	11.75	54.13	xxx
DDC2	39.84 b	8.75	27.79 c	6.00	63.88 a	12.00	43.84	xxx
DDC3	41.61 b	6.50	28.06 c	5.00	76.00 a	13.00	48.56	xxx
DDC4	24.57 b	6.00	18.60 c	5.00	58.61 a	14.00	33.93	xxx
DDC5	37.17 b	9.75	29.85 c	9.00	74.42 a	17.00	47.15	xxx
Yearly CWU and Days	190.89 b	37.00	130.52 c	28.00	361.39 a	67.75	227.60	xxx
Year II Cycles								
DDC6	29.47 b	5.75	24.76 b	4.75	53.64 a	11.00	35.96	xxx
DDC7	21.30 b	3.50	18.19 b	3.25	45.99 a	8.00	28.49	xx
DDC8	25.28 b	4.25	19.43 b	3.50	62.03 a	9.75	35.58	xxx
DDC9	19.08 b	2.75	14.42 b	2.25	46.58 a	6.50	26.69	xxx
DDC10	19.85 b	2.50	14.17 b	2.00	75.09 a	10.75	36.37	xxx
DDC11	28.61 b	4.00	6.02 c	1.00	71.53 a	14.33	35.39	xxx
DDC12	25.57 b	4.50	14.79 c	2.75	51.44 a	9.00	30.60	xxx
DDC13	27.64 b	5.50	24.41 c	4.75	66.74 a	12.50	39.60	xxx
Yearly CWU and Days	196.8 b	32.75	136.19 c	24.25	473.04 a	81.83	268.68	xxx

[1] CWU = ET (mm) summed over total number of days in cycle. Values are the mean of four replications.

[2] Days = Mean number of days treatment remained in cycle before drought-stress was observed.

[3] Test mean = Mean of all treatments for each dry-down cycle.

[4] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

[5] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05.

Table 9: Combined year analysis for stress CWU[1] comparisons based on cycle totals. University of Arizona.

	Pr > F		Mean ET and Duncan's MRT Value[3]	Days[4]	% of Saltgrass CWU
Year[2] (averaged over grass)	0.0236	Year I	227.6 B		
		Year II	268.7 A		
Grass (averaged over year)	<.0001	Saltgrass	417.2 A		100%
		Paspalum	193.8 B		46%
		Tifway	133.3 C		32%
				Year I	
Year x Grass	<.0001	Saltgrass	361.4 A	67.75 A	100%
		Paspalum	190.9 B	37.00 B	53%
		Tifway	130.5 C	28.00 C	36%
				Year II	
		Saltgrass	473.0 A	81.83 A	100%
		Paspalum	196.8 B	32.75 B	42%
		Tifway	136.2 C	24.25 C	29%

[1] CWU = ET Total (mm) summed on an individual lysimeter basis until being removed for visible drought stress.

[2] Year I = 5 Dry-down cycles from June 2 - September 17, 2006. Year II = 8 Dry-down cycles from May 1 - September 14, 2007.

[3] Duncan's New Multiple Range Test. Treatments within an analysis with the same letter(s) are not statistically different. P=0.05.

[4] DAYS = mean number of days treatment remained in dry-down cycle before drought-stress was observed.

Table 10: Combined year analysis for stress Kc[1] comparisons. University of Arizona.

	Pr > F	Mean Kc and Duncan's MRT Value[3]	
Year[2] (averaged over grass)	0.0034	Year I	0.77 A
		Year II	0.72 B
Grass (averaged over year)	0.0014	Saltgrass	0.75 A
		Paspalum	0.76 A
		Tifway	0.73 B
			Year I
Year x Grass	0.0166	Saltgrass	0.76 B
		Paspalum	0.79 A
		Tifway	0.76 AB
			Year II
		Saltgrass	0.74 A
		Paspalum	0.74 A
		Tifway	0.69 B

[1]Kc = [Total Grass ET/Total Reference ET per cycle] summed for cycles 1-13. Twelve values per year, twenty-four values for two years.

[2]Year I = 5 Dry-down cycles from June 2 - September 17, 2006. Year II = 8 dry down cycles from May 1 - September 14, 2007.

[3]Duncan's New Multiple Range Test. Treatments within an analysis with the same letter(s) are not statistically different. P=0.05.

Table 11. Mean crop coefficient (K_c)[1] of three grasses until being removed for visible drought-stress conditions. Summer 2006 and 2007. University of Arizona.

Year I Cycles	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[2]	Significance level[3]
DDC1	0.81 a[4]	0.76 b	0.78 ab	0.78	NS
DDC2	0.72 ab	0.75 a	0.68 b	0.72	x
DDC3	0.89 a	0.84 ab	0.77 b	0.83	x
DDC4	0.70 a	0.66 b	0.72 a	0.69	x
DDC5	0.83 a	0.80 a	0.84 a	0.82	NS
Year II Cycles					
DDC6	0.65 a	0.65 a	0.63 a	0.64	NS
DDC7	0.69 a	0.72 a	0.71 a	0.71	NS
DDC8	0.67 a	0.63 a	0.69 a	0.66	NS
DDC9	0.71 a	0.65 b	0.71 a	0.69	x
DDC10	0.78 a	0.70 b	0.71 b	0.73	xx
DDC11	0.84 a	0.74 b	0.86 a	0.81	xx
DDC12	0.83 a	0.78 a	0.84 a	0.82	NS
DDC13	0.77 a	0.73 a	0.80 a	0.77	NS

[1] K_c developed by dividing cumulative mean ET_a by cumulative ET_o from the initial ET measurement until lysimeter is removed from test due to visible drought-stress. Values are the mean of four replications.

[2] Test mean = Mean of all treatments on each day of measurement.

[3] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

[4] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05

Table 12: Combined year analysis for final K_c[1] before visible drought-stress was observed. University of Arizona.

	Pr > F		Mean ET and Duncan's MRT Value[3]
Year[2] (averaged over grass)	0.0097	Year I	0.69 A
		Year II	0.65 B
Grass (averaged over year)	<.0001	Saltgrass	0.62 C
		Paspalum	0.72 A
		Tifway	0.68 B
			Year I
Year x Grass	0.0004	Saltgrass	0.62 C
		Paspalum	0.77 A
		Tifway	0.70 B
			Year II
		Saltgrass	0.62 B
		Paspalum	0.67 A
		Tifway	0.66 A

[1] Final K_c = The final calculated K_c before lysimeter was removed due observed drought-stress.

[2] Year I = 5 Dry-down cycles from June 2 - September 17, 2006. Year II = 8 Dry-down cycles from May 1 - September 14, 2007.

[3]Duncan's New Multiple Range Test. Treatments within an analysis with the same letter(s) are not statistically different. P=0.05.

Table 13. Mean final coefficient (K_c)[1] of three grasses prior to removal for visible drought-stress conditions. Summer 2006 and 2007. University of Arizona.

Year I Cycles	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[2]	Significance level[3]
DDC1	0.76 a[4]	0.69 b	0.60 c	0.68	xxx
DDC2	0.81 a	0.74 b	0.69 c	0.75	xx
DDC3	0.76 a	0.76 a	0.63 b	0.72	xx
DDC4	0.82 a	0.79 a	0.63 b	0.75	xxx
DDC5	0.72 a	0.52 b	0.54 b	0.59	x
Year II Cycles					
DDC6	0.52 a	0.51 a	0.51 a	0.51	NS
DDC7	0.60 ab	0.68 a	0.52 b	0.60	x
DDC8	0.59 a	0.56 a	0.57 a	0.57	NS
DDC9	0.64 a	0.63 a	0.65 a	0.64	NS
DDC10	0.74 a	0.71 a	0.59 b	0.68	xxx
DDC11	0.79 a	0.74 a	0.78 a	0.77	NS
DDC12	0.78 a	0.70 a	0.66 a	0.71	NS
DDC13	0.74 a	0.74 a	0.68 a	0.72	NS

[1] Final K_c = Mean ET_a divided by mean ET_o on the final day lysimeter was in test.

[2] Test mean = Mean of all treatments on each day of measurement.

[3] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

[4] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05

Table 14: Combined year analysis for number of days[1] lysimeters remained in test before visible drought-stress was observed.

	Pr > F	Mean Kc and Duncan's MRT Value[3]	
Year[2] (averaged over grass)	0.1595	Year I	44.25 A
		Year II	46.28 A
Grass (averaged over year)	<.0001	Saltgrass	74.80 A
		Paspalum	34.88 B
		Tifway	26.13 C
			Year I
Year x Grass	<.0001	Saltgrass	67.75 A
		Paspalum	37.00 B
		Tifway	28.00 C
			Year II
		Saltgrass	81.83 A
		Paspalum	32.75 B
		Tifway	24.25 C

[1]DAYS = number of days lysimeters were in test (all DDC) until drought-stress was expressed (leaf wilting).

[2]Year I = 5 Dry-down cycles from June 2 - September 17, 2006. Year II = 8 dry down cycles from May 1 - September 14, 2007.

[3]Duncan's New Multiple Range Test. Treatments within an analysis with the same letter(s) are not statistically different. P=0.05.

Table 15. Mean number of days[1] three grasses remained in test until visible drought-stress was observed. Summer 2006 and 2007. University of Arizona.

Year I Cycles	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[2]	Significance level[3]
DDC1	6.00 b[4]	3.00 c	11.75 a	6.92	xxx
DDC2	8.75 b	6.00 c	12.00 a	8.92	xxx
DDC3	6.50 b	5.00 b	13.00 a	8.17	xxx
DDC4	6.00 b	5.00 c	14.00 a	8.33	xxx
DDC5	9.75 b	9.00 c	17.00 a	11.92	xxx
Year I Mean	7.4	5.6	13.6	8.8	-
Year I Total	37.00	28.00	67.75	44.25	-
Year II Cycles					
DDC6	5.75 b	4.75 b	11.00 a	7.17	xxx
DDC7	3.50 b	3.25 b	8.00 a	4.92	xx
DDC8	4.25 b	3.50 b	9.75 a	5.83	xxx
DDC9	2.75 b	2.25 b	6.50 a	3.83	xxx
DDC10	2.50 b	2.00 b	10.75 a	5.08	xxx
DDC11	4.00 b	1.00 c	14.33 a	6.44	xxx
DDC12	4.50 b	2.75 c	9.00 a	5.42	xxx
DDC13	5.50 b	4.75 b	12.50 a	7.58	xxx
Year II Mean	4.1	3.0	10.2	5.8	-
Year II Total	32.75	24.25	81.83	46.28	-

[1] Days = mean number of days treatment remained in dry-down cycle before drought stress was observed.

[2] Test mean = Mean of all treatments for each dry-down cycle.

[3] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

[4] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05

Table 16: Combined year analysis for FAW[1] concurrent with visible drought-stress. University of Arizona.

	Pr > F		Mean ET and Duncan's MRT Value[3]
Year[2] (averaged over grass)	0.0044	Year I	0.58 B
		Year II	0.69 A
Grass (averaged over year)	<.0001	Saltgrass	0.41 C
		Paspalum	0.72 B
		Tifway	0.77 A
			Year I
Year x Grass	0.0073	Saltgrass	0.34 C
		Paspalum	0.66 B
		Tifway	0.74 A
			Year II
		Saltgrass	0.48 B
		Paspalum	0.79 A
		Tifway	0.80 A

[1] FAW = fraction of available water on the measurement day when drought-stress was observed.

[2] Year I = 5 Dry-down cycles from June 2 - September 17, 2006. Year II = 8 Dry-down cycles from May 1 - September 14, 2007.

[3]Duncan's New Multiple Range Test. Treatments within an analysis with the same letter(s) are not statistically different. P=0.05.

Table 17. Mean fraction of available water (FAW)[1] of three grasses on the day lysimeter was removed due to visible drought-stress. Summer 2006 and 2007. University of Arizona.

Year I Cycles	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[2]	Significance level[3]
DDC1	0.68 b[4]	0.81 a	0.35 c	0.61	xxx
DDC2	0.56 b	0.64 a	0.33 c	0.51	xxx
DDC3	0.68 b	0.79 a	0.33 c	0.60	xxx
DDC4	0.68 a	0.76 a	0.34 b	0.59	xxx
DDC5	0.66 a	0.71 a	0.35 b	0.57	xxx
Year II Cycles					
DDC6	0.73 a	0.74 a	0.45 b	0.64	xx
DDC7	0.81 a	0.82 a	0.58 b	0.74	xx
DDC8	0.76 a	0.75 a	0.46 b	0.66	xxx
DDC9	0.83 a	0.81 a	0.59 b	0.74	xxx
DDC10	0.85 a	0.81 a	0.34 b	0.67	xxx
DDC11	0.79 a	0.88 a	0.45 b	0.71	xxx
DDC12	0.73 a	0.81 a	0.50 b	0.68	xxx
DDC13	0.81 a	0.78 a	0.48 b	0.69	xxx

[1] FAW developed from soil moisture retention curve.

[2] Test mean = Mean of all treatments on each day of measurement.

[3] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

[4] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05.

Table 18. Mean stress-degree day value (SDD)[1] of three grasses. Summer 2006 and 2007. University of Arizona.

Year I Cycles	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[2]	Significance level[3]
DDC1	8.02 b[4]	1.45 b	15.37 a	8.28	xx
DDC2	6.31 b	7.54 b	27.47 a	13.77	xxx
DDC3	16.92 b	11.24 b	36.24 a	21.47	xx
DDC4	30.14 b	25.80 b	54.46 a	36.80	xxx
DDC5	34.30 b	31.98 b	83.42 a	49.90	xxx
Year I Mean	19.14	15.60	43.39	26.04	-
Year II Cycles					
DDC6	41.67 b	30.94 b	71.91 a	48.17	x
DDC7	22.07 b	14.76 b	49.08 a	28.64	xx
DDC8	6.68 b	4.03 b	23.12 a	11.27	xx
DDC9	8.41 a	7.46 a	8.17 a	8.01	NS
DDC10	5.73 b	4.64 b	18.23 a	9.54	x
DDC11	16.62 b	4.94 c	60.84 a	27.46	xxx
DDC12	27.80 b	20.90 b	50.34 a	33.01	xx
DDC13	25.56 b	23.32 b	51.73 a	33.54	xx
Year II Mean	19.32	13.87	41.68	24.96	-

[1] SDD (°C) developed by the summation of [Tc - Ta] values until lysimeter is removed from test due to visible drought-stress.

[2] Test mean = Mean of all treatments on each day of measurement.

[3] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

[4] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05.

Table 19. Mean critical point model (CPM)[1] of three grasses. Summer 2006 and 2007. University of Arizona.

Year I Cycles	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[2]	Significance level[3]
DDC1	3.42 a[4]	-0.66 b	3.56 a	2.32	xxx
DDC2	-0.03c	4.45 b	7.56 a	4.03	xx
DDC3	3.80 ab	2.14 b	5.80 a	3.91	x
DDC4	8.07 a	8.13 a	9.79 a	8.66	NS
DDC5	9.73 a	10.96 a	13.48 a	11.39	NS
Year I Mean	5.00	5.00	8.04	6.06	-
Year II Cycles					
DDC6	9.27 a	10.54 a	9.63 a	9.81	NS
DDC7	10.55 a	8.56 b	10.54 a	9.88	x
DDC8	3.95 b	2.45 b	7.48 a	4.63	xx
DDC9	6.09 a	6.92 a	1.08 b	4.69	x
DDC10	4.29 a	2.51 a	4.32 a	3.71	NS
DDC11	9.94 ab	4.94 b	12.66 a	9.18	NS
DDC12	8.04 a	9.79 a	10.13 a	9.32	NS
DDC13	9.63 ab	11.28 a	7.45 b	9.45	x
Year II Mean	7.72	7.12	7.91	7.58	-

[1] CPM (°C) = [Tc - Ta] value on day lysimeter is removed from test due to visible drought-stress.

[2] Test mean = Mean of all treatments on each day of measurement.

[3] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

[4] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05.

Table 20. Data from destructive sampling of lysimeters following the conclusion of the test. September 2007. University of Arizona.

	Sea Isle I Paspalum	Tifway Bermuda	A138 Saltgrass	Test mean[9]	Significance level[9]
FAW[1]	0.93 a[7]	0.91 a	0.99 a	0.94	NS
Shoot mass (g)	23.29 a	26.32 a	20.21 a	23.27	NS
Shoot Counts[2]	276.75 a	232.25 a	79.25 b	196.08	xxx
Total Estimated Shoots[3]	2258.97 a	1895.74 a	646.88 b	1600.53	xxx
Leaf Area (cm^2)[4]	16.26 c	17.42 b	21.19 a	18.29	xxx
Estimated Leaf Area[5]	3673.09 a	3302.38 a	1370.73 b	2782.07	xxx
Estimated (LAI)[6]	7.25 a	6.52 a	2.71 b	5.49	xxx

[1] FAW = Fraction of available water after 12 hours of drainage following saturation. Values are the mean of four replications.

[2] Number of shoots per 245 cm^2 disc. One subsample per lysimeter.

[3] Total estimated shoot counts. Total estimated no. shoots/lysimeter. Values are the mean of four replications.

[4] Average cm^2 leaf area of 10 random shoots per lysimeter.

[5] Estimated leaf area = leaf area estimate calculated as (leaf area x number of shoots/10). Values are the mean of four replications.

[6] Estimated LAI = estimated total LA/area of lysimeter. Values are the means of four replications.

[7] Duncan's New Multiple Range Test. Treatments (within rows) with the same letter(s) are not statistically different from each other. P=0.05.

[8] Test mean = Mean of all treatments.

[9] Significance level for ANOVA main affect of "treatment", x, xx, xxx, NS = p level of 0.05, 0.01, 0.001, and non significant, respectively.

APPENDIX A

Soil characterization[1] data for field turf plots. 2007. University of Arizona.

Depth (cm)	0-25	25-50	50-75	75-100
Total Sand	44.8	32.1	71.2	98.0
Very Coarse Sand	2.0	3.7	10.8	28.5
Coarse Sand	3.1	4.4	16.3	43.5
Medium Sand	12.3	6.1	11.8	15.6
Fine Sand	24.1	6.8	21.6	8.9
Very Fine Sand	3.3	11.1	10.7	1.8
Silt	36.2	49.9	19.9	1.0
Clay	19.0	18.0	8.9	1.0
Gravimetric Water Content	14.9	19.4	12.7	3.3
Bulk Density[2]	1.6	1.6	1.6	1.7
Volumetric Water Content[3]	23.8	31.0	20.2	5.6
Munsell Color (Dry)	10 YR 5/3	10 YR 6/3	10 YR 6/3	10 YR 7/3
Munsell Color (Moist)	7.5 YR 4/2	7.5 YR 4/3	7.5 YR 4/3	10 YR 6/3
Textutral Class	loam	loam	coarse sandy loam	gravelly coarse sand
Soil Series: Agua sandy loam (coarse-loamy over sandy, mixed, calcareous, thermic Typic Torrifluvent)				

[1] Soil characterization determined by Particle Size Analysis Method

[2] Estimated bulk density

[3] Volumetric Water Content = Gravimetric Water Content x Bulk Density

APPENDIX B

Measured rainfall events during experiment.

Rain Events: Year 1 — June 2 - September 17, 2006

Date		Amount (mm)	Date		Amount (mm)
21-Jun	**	3.81	4-Aug	**	0.25
25-Jun	**	2.03	8-Aug	**	16.00
26-Jun	**	0.51	13-Aug	**	0.25
27-Jun	**	0.25	14-Aug	**	0.51
7-Jul	**	11.43	16-Aug	**	0.51
18-Jul	**	1.27	22-Aug	†	3.05
25-Jul	***	2.54	4-Sep	†	4.06
27-Jul	**	4.83	6-Sep	†	0.25
28-Jul	***	19.81	7-Sep	†	32.77
29-Jul	**	40.39	8-Sep	†	0.51
31-Jul	**	24.89	12-Sep	**	1.02
3-Aug	**	1.02			
				TOTAL	171.95mm

	No. Events	Amount (mm)
June	4	6.60
July	7	105.16
August	7	21.59
September	5	38.61

Rain Events: Year 2 — May 1 - September 14, 2007

Date		Amount (mm)	Date		Amount (mm)
6-Jul	**	4.32	30-Jul	**	0.76
18-Jul	**	0.25	31-Jul	**	2.54
19-Jul	**	2.29	2-Aug	**	1.52
20-Jul	**	1.78	14-Aug	**	0.51
22-Jul	**	1.78	15-Aug	**	0.25
23-Jul	†	26.16	1-Sep	**	4.06
24-Jul	**	14.48	5-Sep	**	3.56
28-Jul	†	41.91	6-Sep	†	7.62
				TOTAL	113.79mm

	No. Events	Amount (mm)
May	0	0
June	0	0
July	10	96.27
August	3	2.28
September	3	15.24

†Lysimeter was covered to prevent rainfall from affecting ET measurement.
**Adjustment for ET calculation was made by subtracting rainfall amount.
***DDC was terminated due to excessive rainfall.

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