DEFICIT IRRIGATION OF MIXED LANDSCAPES BASED ON TURFGRASS COVERAGE AND REFERENCE EVAPOTRANSPIRATION

By

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To my wife, Angelia Marie Ellison
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<td>K&lt;sub&gt;L&lt;/sub&gt;</td>
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<td>LSD</td>
<td>Least significant difference</td>
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<td>NTEP</td>
<td>National turfgrass evaluation program</td>
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<td>PCA</td>
<td>Project canopy area</td>
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<td>VAC</td>
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Abstract of Thesis Presented to the Graduate School
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DEFICIT IRRIGATION OF MIXED LANDSCAPES
BASED ON TURFGRASS COVERAGE AND REFERENCE EVAPOTRANSPIRATION

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Chair: Richard C. Beeson, Jr.
Cochair: Gail Hansen De Chapman
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Irrigation of landscapes can be responsible for more than half of the water consumption of residential homeowners. The objectives of the research presented here were to test two hypotheses. First, that irrigation frequency based on turfgrass water needs is sufficient for the irrigation of woody shrubs and trees within a mixed landscape. Second, that warm season St Augustine turfgrass can maintain an aesthetically pleasing appearance at irrigation volumes and frequencies less than predicted by ET₀.

Data was collected over a year's period from 1 June 2010 to 31 May 2011 from nine drainage lysimeters at the University of Florida’s Mid-Florida Research and Education Center – Apopka, Florida. Lysimeters had a surface area of 13 m² each and contained two Viburnum odoratissimum, one Magnolia grandiflora 'D.D. Blanchard' magnolia, and 9.7 m² of 'Floratam' St. Augustine turfgrass Stenotaphrum secundatum. Irrigation regimes of 60%, 75% and 90% of ET₀ were adhered to throughout the year. Irrigation occurred when the cumulative depth of ET₀ exceeded 1.90 cm.
All magnolias and viburnum hedges displayed aesthetically pleasing quality, independent of DI level throughout the year. Turfgrass quality varied among DI levels. All turfgrass plots were rated above the minimum acceptable quality.

Results indicate that St Augustine ‘Floratam’ turfgrass can be irrigated at 60% of $\text{ET}_0$ derived from the UN-FAO Penman-Monteith equation in Central Florida, and still maintain acceptable aesthetic quality. This frequency also maintains acceptable quality of magnolia trees and a typical woody hedge if concurrently irrigated at 72% $\text{ET}_0$ based on horizontal canopy project area.
CHAPTER 1
INTRODUCTION

In 1992, turfgrass accounted for 4.4 million acres of maintained area in Florida, of which St. Augustine occupied 1.5 million acres (Hodges et al. 1994). The population of Florida was just under 13 million in 1990, under 16 million in 2000, slightly under 19 million in 2010, and is projected to nearly exceed 22 million by 2020 (Census 2010). The increasing population will likely result in more homes built that require landscape irrigation. Public water use in Florida in 2005 totaled 2.54 billion, gallons/day (USGS 2005). Sixty-one percent of this went to residential water use, with sixty-four percent of that applied as landscape irrigation (Fernald and Purdum 1998).

In general, homeowners have a tendency to over-irrigate their landscapes (Haley et al. 2007). Because irrigation scheduling has historically been based on regular temporal intervals, the same irrigation levels are typically set and applied throughout the seasons with no adjustment for the climatic changes which directly affect landscape plant water needs (Stacia and Dukes 2011). Irrigation with climate-based controllers has the potential to save 20% to 50% of the water consumed by irrigation in residential landscapes (Hilaire et al. 2008).

Since landscape water needs should be based on maintaining turfgrass, tree, shrub, and ornamental aesthetic appeal rather than maximization of growth or even yield; a deficit of the maximum amount of water required can be used (Pittenger et al. 2001). Research has shown that plant material in nursery production (Beeson 2006), agricultural settings (Allen et al. 1998), ornamental settings (Scheiber and Beeson 2007), and established landscapes (Sachs 1991), can be maintained at an aesthetically pleasing level with irrigation based on a percentage of reference evapotranspiration.
The research presented here sought to establish a landscape coefficient based on turf water needs only, yet useful for mixed landscape irrigation scheduling. The coefficient is a correction factor that reduces the amount of water applied to the landscape as a percentage of reference evapotranspiration. By quantifying the relationship between reference evapotranspiration (ET₀) and actual evapotranspiration (ETₐ) the goal was to demonstrate that a landscape coefficient (Kₗ) based on turfgrass water needs only would be sufficient for scheduling irrigation for mixed landscapes. Three levels of deficit irrigation (DI), 60%, 75% and 90% were used to identify the level that maintained acceptable aesthetic quality for the simulated landscapes. In addition this project sought to demonstrate that deficit levels not only could conserve water, but could also limit growth. By limiting unnecessary growth encouraged by excessive irrigation, maintenance costs associated with mowing and trimming would also be reduced. Reduced mowing frequency would also reduce emissions. A 1991 EPA study on non-road emissions found that lawn mowers contribute 16,800 to 23,800 tons per year of emissions (EPA 1991).
Evapotranspiration

Definition and Importance

Evapotranspiration (ET) is the term used to describe water loss from a plant system due to a combination of transpiration and evaporation. Plants transpire by uptake of water through roots, where it is transported through the vascular system (xylem), to exit through stoma as water vapor. Evaporation occurs not only from the edaphic environment, but also from the cell surfaces inside the leaf before the water vapor passes out the stoma. ET is more specifically defined as “the flux density of water vapor just above the canopy, which includes transpiration from the leaves plus evaporation from the soil” (Nobel 1999). ET rates are driven by gradients between the atmosphere and a leaf, within the leaf, and the effect of surrounding surfaces. These gradients are affected by atmospheric conditions, plant physiology, and the characteristics of surrounding surfaces. The importance of ET is linked to the proper scheduling of irrigation events in relation to the climatic demands of the region combined with the measured water use of the crop.

The calculation of ET has its roots in the measurement of evaporation from an open water surface (measured from an open pan or pit) as compared to that of a natural surface (dirt or turf). In 1948, Dr. Howard Penman found that evaporation from a water surface could be correlated to evaporation from a natural surface (Penman 1948). He also observed that for turfgrass, these correlations varied with season and climate. Evaporation from natural surfaces was found to be less than that of open water. In his region of England, it was found that winter evaporation from natural surfaces was
approximately 60% of the open pan evaporation; and summer evaporation from natural surfaces was approximately 80% of the open pan evaporation. This process of measurement and calculation came to be accepted as a good model of evapotranspiration for that specific turf in that specific region.

**Reference ET**

Evapotranspiration (ET) can be expressed as potential ET (PET), reference ET ($\text{ET}_\text{O}$), and actual ET ($\text{ET}_\text{A}$). Penman eventually defined PET as “the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water” (Penman 1948). This would be under ideal growing conditions where the measurements of several climatic factors are used to calculate the maximum evapotranspiration rate of that canopy. PET is calculated by an equation that requires data recorded from an onsite weather station. PET is the basis for $\text{ET}_\text{O}$, and the two are sometimes used interchangeably. More specifically, $\text{ET}_\text{O}$ is the PET that has been calculated from data recorded by a weather station at a specific location, and is used as a reference for that region. $\text{ET}_\text{A}$ is the actual evapotranspiration of a crop.

**Actual ET**

$\text{ET}_\text{A}$ can be determined by several methods. In the water balance method, $\text{ET}_\text{A}$ is calculated simply by measuring the water input into a system (rainfall plus irrigation), then subtracting the measured amount of water that is lost from the system. The system can be under controlled conditions such as a greenhouse or open system located outdoors. Systems can range from a single small container to entire watersheds. The measurement of rainfall and irrigation are straightforward measurements. The water that is lost from a system can be measured based on
drainage volume or weight, such as in a lysimeter (Howell et al. 1991). Lysimeters are a special subset of the water balance method and usually considered an independent method (Howell et al. 1991). Lysimeters consist of a relatively small vessel in which plants are grown with the water balance determined on a fixed schedule, usually daily. These vessels can range from small 4 cm containers to monolithic sections of soil weighing up to $4.54 \times 10^5$ kg (Schneider et al. 1998).

**Calculating ET\textsubscript{O}**

**Evolution of Penman-Monteith**

There are several equations in addition to Penman’s that have been used to estimate ET\textsubscript{O}, each taking into consideration a different combination of climatic variables. However, Penman expressed the idea that a specific combination of atmospheric and solar radiation measurements should be used to calculate ET\textsubscript{O}. The Penman equation calculates ET\textsubscript{O} using daily measurements of temperature, wind speed, relative humidity, and solar radiation providing the most accurate method for daily measurement of ET\textsubscript{O} (Jones 1984). Penman found that it was the combination of these specific factors that would generate the most accurate estimation of evapotranspiration. Later, Monteith improved the accuracy of Penman’s equation (Monteith 1965) by adding factors such as stomatal conductance (or resistance) and hourly climate measurements.

**UN-FAO 56-PM with Tolerances**

In 1998, stomatal resistance values between day and night were added to fine tune the Penman-Monteith equation (Ventura et al. 1999). These improvements helped to develop the widely used version of the Penman-Monteith equation adopted by the Food and Agriculture Organization of the United Nations known as the UN-FAO 56-PM.
It is currently the world standard for calculating $\text{ET}_\text{O}$ based on meteorological data (Irmak et al. 2003a).

**ET$_\text{O}$ in Florida**

Reference evapotranspiration can be calculated by a number of different methods and equations; and is relevant to the climate for which you want data. One of the earliest methods for estimating ET was the pan method. By measuring the rate of evaporation from a round basin of specific diameter and height, termed a “class A” pan, coupling that with crop transpiration data, and correcting with a pan coefficient; one can estimate $\text{ET}_\text{O}$ for a specific region (Irmak et al. 2002). However there are several sources of error with this method (Sivyer et al. 1997) and it has not been reported in the United States since the mid-1990’s. All developed countries use the Penman-Monteith equation or slight variations of it.

One or several equations may be more appropriate for either arid, or for humid climates. Florida is considered a humid climate. Since accuracy of the equations varies with region or climate, data must be collected and inserted into these equations to compare accuracy and assist with equation selection. Comparison with lysimeter data that yield actual evapotranspiration is helpful (Yoder et al. 2005). Some equations, such as the UN-FAO 56-PM, require more detailed climatic data. Others, such as the Turc method, only need temperature and solar radiation data (Irmak et al. 2003b). However in humid climates, relative humidity plays a big role in ET rates (Carrow 1995) and so should be included in calculations. This mandates use of the UN-FAO 56-PM.

ET rates for the commonly used warm-season St. Augustine turfgrass varieties (including ‘Floratam’) were determined in Texas (Atkins et al. 1991), and Georgia (Carrow 1995). These can be used in Florida with a correction factor and applied to $\text{ET}$-
based irrigation scheduling of turf (Haley et al. 2007). In the Haley study, historical ET rates were used to schedule irrigation for residential landscapes. Residential water usage for landscape irrigation was isolated and tracked. It was determined that significant savings in irrigation could be realized using ET based scheduling. Yet when compared to concurrent real time climate data, landscapes were still over-irrigated, emphasizing the need for real time ET based scheduling.

**Determination of ETₐ**

**Water Balance**

Water balance within the plant relies on the uptake of water and the loss of water vapor through the stomata via transpiration (Kramer and Boyer 1995). Proper water status must be maintained to achieve optimum plant growth. The force pulling in water through roots originates in leaves. This is driven by climatic factors such as relative humidity, temperature, and solar radiation. Xylem cells in the leaf and stem can hold water overnight, and thus delay the absorption of water in the morning, causing a lag in water uptake despite moist soil. Therefore, soil water content is not a good measure of plant water status after sunrise (Kramer and Boyer 1995).

**Methods for Measuring ETₐ**

Actual Evapotranspiration (ETₐ) can be found by a number of different methods. In measuring forest ETₐ, four prominent methods were explored and compared (Wilson et al. 2001). Sap flow measurements, eddy covariance measurements, catchment water balance measurements, and soil water budgets were found to correlate on some points, with soil water budgets showing greater potential for inaccuracy. Measuring ETₐ can also be accomplished with the use of a biophysical model know as a lysimeter.
The differences in lysimeters lay in how they are constructed and how the water usage is measured.

**Water Budget**

The hydrological cycle is a closed system that transfers water from the atmosphere to the ground in the form of precipitation. The water is transported in different ways around the earth, and then vaporized back into the atmosphere. Evapotranspiration coupled with precipitation dictates how much water will be available and how a watershed responds to use and precipitation. Water that is evaporated from a region is typically lost from that region. Evapotranspiration provides insight into the water budget of an ecosystem, quantifies water requirements, and plays a role in determining irrigation regimes (Brutsaert 1982).

Water budgets are calculated by measuring the water input into a system minus the water leaving a system. Lysimeters provide a method of precise measure through a closed system to determine water budgets. There are several types of lysimeters which usually fall under the category of either weighing or drainage.

Weighing lysimeters measure the soil water balance via differences in mass measurements throughout the day (Howell et al. 1991). The system is irrigated to field capacity, and then weighed periodically throughout the day or at a fixed time, such as sunrise. As the day progresses the system loses water due to ET\textsubscript{A} causing the system to weigh less. These differences in mass provide water loss data required for calculating ET\textsubscript{A}. By subtracting the water out (measured from the differences in mass) from the water in (precipitation plus irrigation), one can calculate the amount of water loss due to the combination of evaporation and transpiration; or ET\textsubscript{A}. Compared to drainage lysimeters, weighing lysimeters are relatively easy and inexpensive to
construct. However, ET<sub>A</sub> produced by weighing lysimeters not only varies heavily based on the soil characteristics (Kramer and Boyer 1995) but either must be corrected for weight differences resulting from plant growth (Ehret et al. 2001) or measurements must be taken on daily basis in order to minimize this effect.

Drainage lysimeters involve the controlled collection of water through a catchment at the bottom of an enclosed area. This catchment drains to a collection device used to measure the amount of water that has percolated through the soil profile. By subtracting the water out (measured from the catchment) from the water in (precipitation plus irrigation), one can calculate the amount of water loss due to the combination of evaporation and transpiration; or ET<sub>A</sub>. While drainage lysimeters provide the most accurate data (Kramer and Boyer 1995), they require a lot of space, are much more expensive, and are more time consuming to build and maintain. Large drainage lysimeters are also less accurate over short durations due to the lag time caused by the buffering capacity of the soil.

**Crop Coefficient K<sub>C</sub>**

**Defining K<sub>C</sub> Through the Relationship of ET<sub>O</sub> and ET<sub>A</sub>**

Crop coefficients (K<sub>C</sub>) are defined as correction factors that adjust reference evapotranspiration according to region and plant species (Jones, 1984). Many K<sub>C</sub> have been calculated for the different equations that estimate PET or ET<sub>O</sub>. However K<sub>C</sub> are unique to each method and not interchangeable. The most prevalent equation in use is the Penman-Monteith equation. It has been adapted for use with different types of plant material by the calculation of crop specific K<sub>C</sub>'s (Allen et al. 1998). Crop coefficients are calculated as the ratio of ET<sub>A</sub>/ET<sub>O</sub> and are unitless. In practice, a crop is grown in a lysimeter, or a very large uniform expanse if using eddy correlation, located in the
region where the data is needed. \( \text{ET}_A \) can be determined by the water balance method if a lysimeter is employed. Soil moisture sensors are also used in this process. \( \text{ET}_O \) is calculated using daily measurements of temperature, wind speed, relative humidity, and solar radiation near the location. Because \( K_C \) is unitless and \( \text{ET}_O \) is calculated as a depth of water lost, \( \text{ET}_A \) value, if derived from lysimeters, must be converted from volumes or mass to depths of water. In agronomic or grass crops, water loss from the system is divided by the surface area of the lysimeter and sometimes by the leaf area within the lysimeter. For non-agricultural and non-grass crops, such as potted plants or container- grown nursery crops or ornamental trees, the normalizing volumes or mass to a depth of water becomes more problematic.

Since the Penman-Monteith equation is based on a reference crop of short grass, the ratio of \( \text{ET}_A/\text{ET}_O \) corrects the ET rate for the crop of interest. The resulting \( K_C \) value can be used in models to schedule irrigation (Beeson 2005). This is accomplished by monitoring the environment in a region via a weather station. \( \text{ET}_O \) is then calculated and multiplied by \( K_C \) to estimate the amount of water to apply with the goal of achieving maximum growth or crop yield.

**Examples of How \( K_C \) is Used**

By combining the Penman-Monteith calculations and lysimeter data, many crop coefficients have been determined and used successfully to schedule irrigation for individual agricultural crops (Fereres and Soriano 2007); as well as container plant production. A \( K_C \) of 0.59 was determined for *Rhododendron sp. 'Formosa’* that could be used to schedule irrigation for container production (Beeson 1993). Irrigation models for container production of *Ligustrum japonicum* based on the relationship between \( \text{ET}_O \) and \( \text{ET}_A \) have been successfully correlated to \( K_C \) along with the use of canopy projected
surface area (CPSA) (Beeson 2005). Modeling of ET\(_A\) was also successful for \(A.\) \textit{rubrum} (Beeson and Brooks 2006b) providing data useful for calculating acceptable \(K_C\) values for container production.

Stomatal conductance (\(g_S\)) in Sweet gum \textit{Liquidambar styraciflua} were studied concurrently in Utah, Texas, and Florida to determine the relationship between \(ET_O\), vapor pressure deficits (VPD), and water loss through transpiration (\(T_{SW}\)) (Kjelgren et al. 2004). Subsets of trees grown in each location were shipped overnight to the other locations, with \(g_S\) and \(ET_A\) measured over a two week period. For the first few days after shipping, stomata responded to their previous environment, not the one they were moved to. By the second week stomata responded to the \textit{in situ} environment. Because the stomata were still responding to their previous environment, \(K_C\) from western trees shipped to Florida were initially lower than remaining Florida trees and differed from \(K_C\) calculated the second week after shipping. Conversely, Florida trees shipped to arid climates maintained high \(g_S\) the first few days until acclimatizing to the much higher VPDs and near constant winds. These results suggest that local analysis of transpiration is needed to properly calculate water needs index (WNI) \(K_C\) values, especially between arid and humid climates. Daily crop water use was also examined in relationship to \(ET_O\) in container-grown ornamentals over various climates throughout California (Burger et al. 1987, Schuch and Burger 1997). Water use varied heavily between locations due to variance in climatic factors such as wind and solar radiation, emphasizing the importance of the use of local, real time climatic data for the calculation of \(ET_O\) and the importance of measurement of regional \(ET_A\) values.
Even when properly spaced, $K_C$ for container plants were shown to be considerably higher than those values found for field crops (Schuch and Burger 1997). This may have been because $K_C$ was based on container surface area while crop coefficients are based on large ground areas. Although the relationship between $ET_O$ and $ET_A$ was apparent, the resulting $K_C$ values varied heavily not only between locations, but also between plant species and time of year; emphasizing the need for $K_C$ to be sensitive to location, specific species, and variances throughout the growing season (Garcia-Navarro et al. 2004). Because of the difficulty in relating $K_C$ calculated for container plants and $K_C$ calculated for field crops due to the difference in surface area (Schuch and Burger 1997), these studies for $K_C$ values for container grown plants are useful for nursery production but may be of limited use in the landscape.

The water use of plants grown in production containers was measured and compared to the water use of plants grown in large lysimeters of field soil. Container plant water use, although overall more than the water use of plants grown in lysimeters, correlated with plants in lysimeters. This may prove helpful in grouping plants within the landscape according to water use; which in fact helps in the landscape design process (Garcia-Navarro et al. 2004). In California, many common landscape plants have been assigned recommended ranges of $K_C$ and collected under a listing known as WUCOLS (Water Use Classification of Landscape Species) (Pittenger et al. 2008).

Turfgrasses have demonstrated lower $ET_A$ when compared to $ET_O$ (Jones 1984), indicating the potential for water savings if turf irrigation is managed using ET-based scheduling. Cool season and warm season turfgrass responses should be considered separately. In general, cool season grasses have been shown to have a higher water
demand than warm season turfgrasses (Feldhake and Butler 1983). It was also found that management practices and microclimates significantly impacted ET rates of cool season grasses (Feldhake and Butler 1983).

St. Augustine turfgrass ET rates were determined to have a range from 0.63 to 0.96 cm/day in an arid climate (Beard 1985). Soil moisture probes were later used to determine that ET rates for a ‘Raleigh’ St. Augustine turfgrass ranged from 0.15 to 0.56 cm/day in a humid climate (Carrow 1995). ET₀ calculations using the pan method were also compared to the Penman method. Using both to calculate Kₑ values, the author noted that the pan method produced different coefficients (0.53 to 0.89) than the Penman method (0.52 to 1.01). However, both methods indicated the potential to irrigate warm season turfgrass in a humid climate at less than ET₀. The pan results are also close to those of (Meyer and Gibeault 1987) who found Kₑ values for warm season grasses in general to range from 0.54 to 0.79. Seasonal variations for ET rates were high and varied among turfgrass species. Monthly averages of Kₑ values and species specific Kₑ values could provide more accurate irrigation scheduling (Carrow 1995). In Nevada (Devitt et al. 1992) and Arizona (Brown et al. 2001) useful monthly Kₑ values were developed for bermudagrass over-seeded with ryegrass. In Central Florida, Kₑ values from eddy correlation were found for bahiagrass (Jia et al. 2009), a widely used foliage grass employed as turfgrass due to its apparent drought tolerance mechanisms. Kₑ values spiked upwards of 0.90 during the warmer months and dipped as low as 0.35 during cool months.

Results for warm season turfgrass in the South Florida region indicate that ETₐ generally occurred below ET₀ in the mid-1960's (Jones 1984). Kₑ values ranged from
0.85 to 0.92 year-round. This consistency suggests the potential for incorporating a constant $K_C$ into irrigation-conserving scheduling year round for this region. However, while results indicating that a single crop coefficient based on an annual average may be suitable for irrigation scheduling in South Florida, results from other regions differ, such as those from Georgia (Carrow 1995), the more arid Nevada (Devitt et al. 1992), or Arizona (Brown et al. 2001). In these regions crop coefficients suitable to these climates require seasonal or even monthly adjustment, reinforcing the need to provide regional ET data for calculation of crop coefficients.

In the humid southeastern and Gulf coast climates, warm season turfgrass $E_{TA}$ rates are significantly lower under humid conditions than reference ET (Carrow 1995). Soil properties are also a significant factor in determining root expansion. These results reinforce the importance of regional $E_{TO}$ (Carrow 1995). In Florida, St. Augustine ‘Floratam’ managed with ET-based irrigation controllers had 20-59% reduction in water use from maximum ET (McCready et al. 2009). Aside from these studies, crop coefficient data on warm season turfgrasses in humid climates, specifically in Central Florida, has not been reported (Irmak et al. 2003a). Haley et al. (2007) also called for more work in this area, reinforcing the idea that crop coefficient values for turfgrasses in Florida have not been documented.

Two ET irrigation controllers were compared along with soil moisture sensor-based irrigation controllers, standard timers with rain sensors, and standard timers alone for turfgrass irrigation management (McCready et al. 2009). The standard timers alone irrigated on a set schedule of two days per week. The rest were controlled by the data sensors they employed. Turfgrass quality was visually rated using the National
Turfgrass Evaluation Program (NTEP). $\text{ET}_0$ was derived from a nearby weather station using the Penman method. When $\text{ET}_A$ was compared between plots, variability was significant. Pre-determined $K_C$ values, provided by the manufacturer of the ET controllers, were used to correct $\text{ET}_0$ and integrated into the scheduling of irrigation events for the ET controllers. All controllers demonstrated a significant water savings over the standard timer by itself. Coupled with better than acceptable visual ratings, the Toro ET controller had the highest water savings of 62%. However, there were problems with the programming of the other ET controller which produced less than acceptable turf quality ratings. This indicates that differences in controller setup and human error can still affect controllers based on ET. This study also demonstrates the direct application of crop coefficients in scheduling irrigation events and the potential for superior water savings compared to other typically used controllers in the residential landscape.

In California, four ET controllers were compared for ease of use and accuracy for scheduling irrigation events based on real time climatic data and plant factors (Pittenger et al. 2004). Plant factors are a term used in this study to describe crop coefficients for ornamental landscape plant material and used in correcting $\text{ET}_0$ for residential irrigation scheduling. Results were highly varied, with one controller proving easier to use, while others were commented to require a professional to set it up. Accuracy was also highly variable with only one providing relatively accurate scheduling, while another grossly over irrigated, and yet another under irrigated. It was concluded that while the use of ET controllers possess the potential for significant water savings, they are still subject to inaccuracies based on design, calculation, and human input. More research involving
direct application of these controllers needs to be done to help in bringing user friendly, reliable, and accurate ET irrigation management into the mainstream usage.

**K<sub>C</sub> Use in Established and Mixed Landscapes (K<sub>L</sub>)**

Applying the crop coefficient method to urban landscapes is difficult. Typical urban landscapes are much smaller than agricultural fields, yet when an urban landscape is viewed as an entire neighborhood; it could be likened to an agricultural field. However, there is currently no system for collaboration between neighbors in an urban setting concerning irrigation. Urban landscapes normally contain a mixture of species, as opposed to a single species. Since each species could have an individual crop coefficient, measurement and calculation of K<sub>C</sub> becomes more challenging. Finally, both agricultural crops (Allen et al. 1998) and nursery crops (Beeson and Brooks 2006a) are usually irrigated in a manner that will maximize yield and minimize time to marketable size. In established urban landscapes though, the goal is not to maximize yield or growth but simply maintain aesthetically appealing and healthy plants in a sustainable landscape setting (Sachs et al. 1975). This requires different irrigation models than those used to reach the levels of growth desired in agriculture and nursery production. Therefore, concerning landscapes, we must adjust the concept of the crop coefficient to align with aesthetics and sustainability as opposed to agricultural and production goals. The concept of a landscape coefficient (K<sub>L</sub>) was born from this idea.

Early work in California suggested that established landscape plantings can survive at acceptable aesthetic levels with irrigation below that generally accepted or typically employed (Sachs et al. 1975). Sachs evaluated shrub and ground cover plantings that were allowed to become established over a period of two years for the ground covers and five years for the shrubs (Sachs et al. 1975). Irrigation was
performed using flooded trenches and applied at high volume (>9cm) at three levels: bi-
monthly, monthly, and none at all. He found that many species performed acceptably
with bi-monthly or even no supplemental irrigation. This may have been due in part to
the high water holding capacity of the clay soils in that region. Although a coefficient
was not discussed, and irrigation was not based on ET, this was the first published
research concerning reduced irrigation in established landscapes. The results provide
early evidence that species-specific irrigation and plant grouping in the landscape could
reduce and normalize irrigation requirements for aesthetic purposes. This would have
the added benefit of reducing pruning and fertilization needs.

Later Sachs revisited results from one of his mid-1970’s studies comparing actual
water applied via irrigation to pan evaporation measurements for ET₀ (Sachs 1991).
These hedgerows were established in 1965, then six years later were subjected to
irrigation levels at 100% ET₀, an unspecified fraction of ET₀, and finally zero. Again
shrubs not only survived, but pruning of excess growth was minimized because shoot
growth has a direct correlation with irrigation frequency and subsequent soil available
water (Sachs 1991). There was discussion that leaf temperature could be used to
determine plant water needs and subsequent irrigation requirements, but Sachs
concluded that high wind speeds would negate this assumption.

In 2004, newer research was published on the potential water savings by
irrigating established landscapes based on a percentage of ET₀. Plots were
established with a mixture of plant materials from thirty genera. Aesthetic performance
was observed at rates of 0.36, 0.18, and 0.0 of ET₀ (Shaw and Pittenger 2003). Of the
30 genera, eight had acceptable performance at 0.0 ET₀. Thirteen genera
demonstrated acceptable aesthetic levels at the 0.18 ET\textsubscript{O} level. Only two genera, *Hibiscus* and *Ligustrum*, still appeared under-irrigated at 0.36 of ET\textsubscript{O}. These results provide additional evidence for genus or species relevant K\textsubscript{C} values in the use of a mixed landscape coefficient. They also suggest that an accurate K\textsubscript{L} is achievable if plants are grouped based on water needs, or irrigation is based on the K\textsubscript{C} of the most water needy plant. The authors stressed the importance of further work in this area in order to clarify the differences between species specific K\textsubscript{C} and group K\textsubscript{C}.

Mixed landscape water usage based on ET was finally addressed in 2010. In pursuit of K\textsubscript{L}, soil moisture sensors and in-ground gravimetric lysimeters with vacuum-assisted leachate removal were employed (Pannkuk et al. 2010). ET\textsubscript{A} was calculated from sensor data, with ET\textsubscript{O} calculated using the Penman-Monteith equation. Landscapes were established in two locations, one in College Station, TX and the other in San Antonio, TX. They consisted of St. Augustine turfgrass only, St. Augustine turfgrass and Shumard Oak tree, Shumard Oak tree only, native grasses only, and Shumard Oak tree and native grasses.

The results were greatly affected by soil salinity levels in College station, as well as by unusually low precipitation amounts that were more than 80% below average in San Antonio during the two year study. Overall, native grass landscapes had a low coefficient of 0.3 in College station, while San Antonio's native grass landscapes had a much higher coefficient of 0.61, with a peak of 0.8 in the later part of the year. St. Augustine only and oak only had coefficients of 0.34 and 0.21 in College Station, with values of 0.52 and 0.43 in San Antonio respectively. The tree and turfgrass results
were similar to turfgrass only, while the tree and native grass mix was similar to native grass only.

The authors explained their results by stating that the taller native grasses had more leaf area due to height, and may be opportunistic water users in favorable settings (Pannkuk et al. 2010). This brings up the discrepancy in using agricultural and nursery production ET calculations because the big leaf model may not be as accurate in varying landscape settings where height must also be considered when calculating leaf area available for transpiration. They speculated that a $K_L$ of 0.7 may save water, but could not support this based on field data. It was also suggested that a seasonal structure of $K_L$ would be 0.5 for early in the year, 0.6 for mid year, and end at 0.7 for later in the year (Pannkuk et al. 2010). Additional research was recommended to compare aesthetics and irrigation at levels below $E_T$.

**Deficit Irrigation**

**Definition and Importance**

Deficit irrigation can be defined as the practice of irrigating agricultural crops, container plants, or established landscapes at less than 100% $E_T$. It can further be defined as the practice of irrigating to a lower percentage of a known crop coefficient or lower than a known landscape coefficient. A useful percentage can be found by observing individual crop, plant, or landscape performance under pre-set deficits of $K_C$ or $K_L$. Performance can be measured by yield, growth, or aesthetic rating (McCready et al. 2009). Deficit irrigation has been successfully employed in both agricultural production of maize (Kang et al. 2000) and container production of woody ornamentals (Beeson 2006), achieving equivalent or better yields and growth. Deficit irrigation also
has the potential to meet the goal of maintaining an aesthetically pleasing landscape while at the same time reducing residential water use.

**Effect on Aesthetics**

Container plants such as *Viburnum odoratissimum*, a commonly used hedge in Florida landscapes, were shown to achieve acceptable growth and maintain acceptable aesthetic quality under deficit irrigation (Beeson 2010) when canopy closure was taken into account. In Florida, coleus subjected to deficit irrigation levels also maintained acceptable aesthetic levels (Scheiber and Beeson 2007). In Colorado, several herbaceous annual ornamentals irrigated based on deficits of ET\textsubscript{O} provided mixed results. Some species such as *Impatiens walleriana* only did well at 100% ET\textsubscript{O} while others such as *Lobularia maritima* and *Pelargonium x hortorum* did well with 25 to 50% of ET\textsubscript{O} (Henson et al. 2006). In California, it was demonstrated that ornamentals could be grown in the landscape and subjected to irrigation levels that could be considered deficits, while still maintaining acceptable aesthetic levels (Sachs et al. 1975, Sachs 1991)

Cool season turfgrasses maintained in Colorado under deficit irrigation regimes showed acceptable aesthetic quality up to a 27% reduction of ET\textsubscript{O} (Feldhake and Butler 1984). However, a significant decline in quality was noted beyond the 27% reduction mark. Although St. Augustine is not known to be a drought tolerant turfgrass, it has shown some tendency toward physiological adaptation to drought stress. In studies of dehydration tolerance, 'Texas common' St. Augustine demonstrated a high dehydration tolerance (Beard 1989). Further, St. Augustine achieved acceptable root growth under deficit irrigation during the establishment period (Sinclair et al. 2011). This indicates the
possibility of a wider range of tolerance for warm season grasses such as St. Augustine, under deficit irrigation regimes, for maintaining acceptable aesthetic levels.

**Growth Versus Aesthetic Quality**

 Woody ornamental trees demonstrated controlled growth with a strong tolerance to deficit irrigation, some even with an increase in quality due to shorter internodes (Cameron et al. 2006). The rate of shoot growth is directly correlated to the rate of irrigation. As irrigation frequency increases, so does shoot growth (Stabler and Martin 2000). Although many plants are installed in the landscape for their desirable drought tolerances, they are often overwatered and subsequently require more frequent pruning. Less frequent irrigation results in reduced shoot growth while maintaining vigor (Sachs et al. 1975). Widespread application of deficit irrigation could result in reduced maintenance requirements by reducing the need for frequent pruning.

 Aesthetic evaluation for turfgrass finds a standard in the National Turfgrass Evaluation Program (NTEP) (Morris and Shearman 2008). This program provides a rating scale of one to nine, nine being perfect. A visual rating guide is used, with ratings one through eight pictured. Since 9 is the theoretical ideal, it is not pictured on the rating sheet. At the NTEP website, a rating of six or better is said to be commonly accepted as adequate. However, the authors go further to explain that quality ratings differ among turfgrass types, and that a minimum of six for one species may not necessarily be the minimum for another. A study in Florida assigned the minimum acceptable rating for St. Augustine at five, and this was the value employed in this research (McCready et al. 2009).
Application of $K_L$

Residential Landscapes

Simplification of landscape irrigation is necessary to compensate for poor homeowner management of automated irrigation systems. Maintenance, calibration, accuracy, and seasonal adjustments are just a few areas where property owners fail in managing their irrigation systems (Dukes 2011). There have been numerous attempts at simplifying the process by recommending "deep and infrequent" irrigation, providing depth of irrigation conversions for timers, and incorporating irrigation calculators in Florida’s F.A.W.N. (Florida Automated Weather Network) system. F.A.W.N. provides up-to-date statewide climatic data to assist homeowners in making seasonal adjustments to irrigation schedules with limited effort (Dukes 2011). Still, improper scheduling of residential irrigation remains prevalent (Baum 2005).

The purpose of determining ET rates and $K_L$ values is so that efficient and effective irrigation of suburban landscapes can take place. The typical residential landscape contains a mixture of trees, shrubs, ornamentals, and turf. If a mixed landscape can be irrigated based on turf area or mixed landscape area, it would eliminate the need to determine crop coefficients of each plant and then combine them.

Potential of ET Based Irrigation

ET based irrigation controllers have become more available to homeowners in recent years. ET based controllers offer automated irrigation scheduling based on real time climatic data. This data can be recorded throughout the region and communicated wirelessly to a controller integrated into the typical residential irrigation system (Stacia and Dukes 2011). In theory, this type of system provides the climatic and seasonal adjustments required for efficient irrigation without the need of homeowner input once
installed. When properly installed and managed, ET based irrigation controllers demonstrated a 43% annual water savings compared to other types of controllers (Stacia and Dukes 2011).

In San Antonio Texas, the potential for ET-based irrigation was examined by recruiting homeowners to participate in a study where landscapes were irrigated based on 100%, 75%, and 50% of $E_{TO}$ for one full year. During this time the participants were asked to rate the turf based on a one to five scale, one being excellent; five being poor. On average, turf could be managed effectively with the lower coefficients of 0.75 and 0.50, while staying below the three rating for the summer, and below the two rating otherwise (Pope and Fipps 2000). Classes and communication channels were established which encouraged enthusiasm for the project among the participants.

There are advancements in ET related technology that have the potential to go beyond what is currently available. Artificial intelligence is being used to produce $E_{TO}$ that can be transmitted to undeveloped regions that cannot produce $E_{TO}$ data by measuring climatic data locally (Adeloye et al. 2011). These types of research and results clearly indicate the need not only for an interactive program to encourage homeowner participation but also the need for accurate data concerning the irrigation of landscapes based on the ratio of actual plant water use and real time climatic data.
CHAPTER 3
MATERIALS AND METHODS

Eighteen drainage lysimeters were constructed into a hill-side such that only the west facing wall was fully exposed (Figure 3-1). Lysimeters were installed in three blocks of three lysimeters in two rows oriented north-south.

Figure 3-1. Drainage lysimeters on the west row after construction. The pipe exiting the bottom was connected to a system designed for leachate collection. The white pipes on the right were for irrigation. Photo courtesy of Scott Simpson.

Inside dimensions of each lysimeter were 3.3 m north-south and 4.1 m east-west for a total surface area of 13.33 ± 0.05 m². The bottom of each was sloped towards the center with a single drain pipe exiting the west wall for drainage collection. Inside walls were painted with basement wall waterproof paint (Seal-Krete DampLock, Convenience Products, Auburndale, FL) in two coats. The drainage system consist of a central junction box over the center drain hole with geo-textile sock covered 10 cm corrugated drain pipe extending to diagonal corners (Figure 3-2). These were covered with rock,
textile cloth, and coarse sand before backfilling with native soil; Apopka fine sand series came from sand-loam marine sediment, usually has loam; and are siliceous, hyperthermic, grossarenic, and paleudults (USDA 1989). Lysimeters are 147 cm deep along the outside edge and 155 cm deep in the middle.

Figure 3-2. Installed drain line prior to covering with rock and sand. Photo courtesy of Richard Beeson.

For this project, only the nine spatially adjacent lysimeters on the north end of the two rows were utilized. After soil was leveled, turfgrass irrigation was installed. This consisted of 1.9 cm polyvinyl chloride (PVC) pipe buried around the inside perimeter of each lysimeter. Pop-up spray heads (PRO S-06-10A, Hunter Industries, Inc., San Marcos, CA) were positioned at each corner and in the center along the north and south sides. The northeast pop-up was inset 0.9 m from the corner to accommodate the shrub bed. Turfgrass and woody plant irrigation were controlled separately using two 24 VAC solenoid valves (SRV, Hunter Industries, San Marcos, CA), each regulated with
a 167 kPa pressure regulator (PMR-MF-25, Senninger Irrigation Inc., Clermont, FL). Woody plant irrigation was distributed using 1.9 cm black polyethylene tubing (I.P.S flexible PVC tubing, The Toro Company, Bloomington, MN) to both the tree and shrubs.

The tree irrigation employed two 30 cm tree stakes with 13.2 L hr⁻¹ nozzles and inverted cone spreaders (Jain Irrigation Inc., Fresno, CA). Shrub irrigation employed the same spray stake assembly but with four 7.1L hr⁻¹ nozzles. One stake was placed between each plant and along both outside edges. Irrigation valves were positioned on the outside the west-facing wall. One water meter (C700-SF, Elster-Amco, Ocala, FL) with an electronic counter (123 counts L⁻¹) was installed after each valve and before the pressure regulator.

In August 2009, the drainage lysimeters were randomly assigned to treatments. Since two independent experiments were to be conducted concurrently, the site was split spatially based on what was considered to result in the most uniform microclimate per experiment. This experiment was designated to occupy the northern six lysimeters of the west row and northern three lysimeters of the east row (Figure 3-3).

Figure 3-3. A view of lysimeter project looking from south to north. Photo courtesy of Scott Simpson.
The experiment consists of nine identical mixed landscape plantings. Each plot layout contained one magnolia (‘D.D. Blanchard’, *Magnolia grandiflora*) planted in the center of each lysimeter east–west and 1.1 m north of the south wall. It was surrounded with an area of 1.1 m² of mulch. A shrub hedge of sweet viburnum (*Viburnum odoratissimum*), mulched 1.0 m wide (north-south) and 2.0 m long (east-west) in the northeast corner completed the layout. This hedge consisted of two plants.

The 9 lysimeters were spatially divided into three replicate blocks. Lysimeters within each block were randomly assigned one of three deficit irrigation (DI) treatments. These consisted of counting 90% of daily $E_T$ towards an accumulated irrigation depth (90% DI), counting 75% of daily $E_T$ towards an accumulated irrigation depth (75% DI) or counting 60% of daily $E_T$ toward an accumulated irrigation depth (60% DI). Irrigation was applied to a lysimeter when the cumulative irrigation depth exceeded 1.90 cm. Thus treatments applied 10%, 25%, and 40% less irrigation for the 90%, 75%, and 60% DI, respectively, than that calculate to replace $E_T$ lost by a well-irrigated, maintained cool season turfgrass.

On 9 September 2009, the magnolias and viburnums were transplanted into each of the lysimeters according the layout described above (Figure 3-4). The magnolias were approximately 1.8 m tall and 3.8 cm in caliper measured at 15 cm above ground. They were transplanted from 51 cm Root Control Bags (Root Control, Inc, Stillwater, OK.). Viburnums were transplanted from 11.4 L containers. At transplanting, backfill soil was watered-in to insure good contact between root balls and the soil. Excess soil was removed from lysimeters. The micro-irrigation described above was installed in
each lysimeter on 10 September and both species were irrigated to establishment using micro-irrigation on alternate days thereafter through late May 2010.

After transplanting, tree and shrub dimensions were measured tri-weekly and used for aesthetic evaluation. Shrub measurements consisted of average width north-south (perpendicular to the long axis of the hedge) and east-west (parallel to the long axis of the hedge), and average hedge height. Hedges were pruned as needed to maintain maximum dimensions of 1 m north-south and 2 m east-west. Magnolia canopies were measured at the widest width and the width perpendicular to the widest width. Tree height to the terminal bud was also measured. In addition, trunk circumference was measured 15 cm above the soil. Magnolia trees were not pruned. Canopy widths were multiplied to calculate a horizontal projected canopy area (PCA, m²) for each hedge and tree. PCA was multiplied by height to calculate canopy volume (GI,m³)

Figure 3-4. A view of an example of one of the nine lysimeters shortly after transplanting. Photo courtesy of Scott Simpson.
The remaining surface area (75%) was covered with St Augustine turfgrass (Stenotaphrum secundatum [Walt.] Kuntze) ‘Floratam’ (Figure 3-4). Fresh cut sod was delivered from a turfgrass farm near Lake Okeechobee, FL on 24 September 2009. This turfgrass was cut from a sand soil to be compatible with the sand soils in the lysimeters. It was installed on 25 September, and required an aggressive irrigation schedule to facilitate establishment. The turfgrass system irrigated three times per day for 30 minutes to wet both the sod and soil beneath. The turfgrass irrigation schedule was changed to four times per day for 15 minutes on 29 September, and then reduced back to three times per day on 12 October. It was further reduced to twice per day on 15 October, to once daily on 20 October, to once every two days on 2 November, to every three days on 11 December, and finally every four days on 6 December.

Turfgrass in each lysimeter was first fertilized at 453 g N per 93 m² with a granular fertilizer (Vigoro All Purpose Plant Food 10-10-10, Vigoro, Sylacauga, AL) on 30 October 2009 using a 46 cm wide Accugreen drop spreader (Scott's, Marysville, OH). Subsequent turfgrass fertilization occurred in 2010 on 7 May and again in 13 July. Fertilization continued throughout the experiment based on original and then more recent Institute of Food and Agricultural Sciences (IFAS) residential turfgrass general recommendations (IFAS publications SL21 & ENH1089). Pesticides and fungicides were applied as needed to control chinch bugs (Blissus insularis Barber) and gray leaf spot (Pyricularia grisea) respectively. The magnolias and viburnum were first fertilized after transplanting on 26 February 2010 with a slow release nitrogen granular fertilizer (16-4-8 ProSource One, Agro Distribution, Memphis, TN), corresponding with the first
pruning of the viburnum. Initial measurements for both magnolias and viburnum for 2010 occurred on 15 March.

Hard freezes occurred each morning from 7 to 10 December 2009, freezing all grass blades. Hard freezes occurred again eight of the first twelve days of January 2010. Woody plants were not injured, but there were no green leaves in the turf grass by 12 January. The rest of January through March remained unusually cold, with several more freezes. By early July 2010 it was concluded that too much of the turfgrass did not recover from the winter and had to be replaced (Figure 3-5). Dead sod was removed 15 and 16 July 2010. For some lysimeters up to 25% of the turfgrass was replaced, most were around 15%. Turfgrass was replaced on 19 July 2010. Irrigation remained under computer control. To facilitate establishment, the new sod was lightly sprayed with a hose by hand twice daily for four weeks when it did not rain.

Figure 3-5. Freeze damage to turfgrass from winter of 2009-2010, shown here in mid-July 2010. Photo courtesy of Scott Simpson.
The system to quantify leachate was sheltered and sealed from the elements as described below. A dry well was installed below the 5 cm drain pipe to support the measuring device and to allow for its greater depth below the drain pipe (Figure 3-6). This device consisted of an upper collection vessel constructed from a 15 cm PVC schedule 40 cap and a 15 cm length 15 cm diameter schedule 40 pipe with a ~1.5L volume that drained into a weighing vessel through a normally open valve (Series 8262, ASCO, Florham Park, NJ). The weighing vessel was similar to the collection vessel, but was constructed using a 45 cm long PVC pipe with a normally closed valve (DSVP11-8PX8SFX1, Deltrol Controls, Milwaukee, WI) at the bottom. It was suspended from a 22.7 kg load cell (SSM-AJ-50, Interface Inc, Scottsdale, AZ) has an overflow drain near the top to channel excess water below the drain valve should leachate exceed the capacity of the system. The maximum capacity was 1.5 L per two minute cycle.

Figure 3-6. Measuring device for quantifying leachate from each lysimeter. The upper vessel collects water which drains to the weighing vessel (bottom) through the normally open valve (green and gold). The system is supported by the T-frame above the dry well, shown by arrow. Photo courtesy of Scott Simpson.
In operation, a data logger (CR1000, Campbell Scientific Inc., Logan, UT) measured the leachate volume every two minutes and activated the system when a minimum of 1.001 L had been collected. Twelve VDC power was shunted to the valves to close the upper valve, and open the drain valve to evacuate the weighing vessel. When water drainage was <5 mL per ten seconds, the 12 VDC power was turned off and the system is reset. This system has an overall capacity to measure around 12.7 cm of rainfall every twenty-four hours, assuming the soil volume is at field capacity initially. Each measuring device was enclosed within a structure consisting of a tin roof and cement board sides (Hardie board, James Hardie, Mission Viejo, CA) which was sealed with silicon and expanding foam to exclude rainfall, dust and blowing sand (Figure 3-7).

![Sealed shed which housed the leachate measuring device spring 2010.](image)

**Figure 3-7.** Sealed shed which housed the leachate measuring device spring 2010. Photo courtesy of Scott Simpson.

Two AM16-32 multiplexers (Campbell Scientific, Inc.) with associated wiring and terminal strips were installed for measuring mass of the weighing vessels. Data logger-
controlled remote relays (SDM-CD16AC, Campbell Scientific, Inc.) were installed for control of the leachate measuring and irrigation valves. Electrical power was supplied by 24 VAC and 12 VDC transformers (Figure 3-8).

Figure 3-8. Data collection and irrigation control system for the drainage lysimeter project. Photo courtesy of Richard Beeson.

The lysimeter system was controlled by an original algorithm that achieved operational status on 26 May 2010, during the plant establishment phase (R Beeson, pers. comm). Highlights of the algorithm are described below. Each lysimeter was treated independently for all operations.

The system weighed each weighing vessel every two minutes and the amount drained was added to a running daily total. At 5 am (Eastern Standard Time, EST), the running total was stored, reset to zero, and data collection began anew. At midnight, cumulative daily rainfall and reference evapotranspiration was calculated using
Campbell Scientific Inc., Application Note 4 and transferred from the onsite weather station located in a grassy field ~100 m west of the site to the CR1000 via a common desktop computer (model W3609, eMachines, Irvine, CA). The weather station consisted of a LI200X pyranometer (Li-Cor Inc, Lincoln, NE), a CS215 temperature and relative humidity probe (Campbell Scientific, Inc.), a Wind sentry set (03001, R.M. Young Co., Traverse City, MI), and a tipping bucket rain gauge (TE525, Texas Electronics, Dallas, TX) connected to a CR10X data logger (Campbell Scientific, Inc.). Should the transfer fail, a backup of 0.46 cm of ET₀ was assumed by the algorithm.

Daily ET₀ was then multiplied by one of three treatment coefficients. The control coefficient was 0.90. This was the Kᵦ, established previously, that supported aesthetically pleasing St Augustine ‘Floratam’ in Central Florida (M. Dukes, pers. comm). The other two coefficients were hypothesized to be a moderate reduction in irrigation rate (Kᵦ = 0.75) that would likely produce acceptable quality, and a severe reduction (Kᵦ = 0.60) that would likely result in unacceptable quality. Cumulative totals of the adjusted ET₀’s for each lysimeter were retained by the data logger. When cumulative ET₀ for a lysimeter exceeded 1.90 cm, the actual cumulative ET₀ was multiplied by the turf grass area (10.0 m²) to calculate the volume of irrigation to apply to the turf. Similarly the same actual cumulative ET₀ was multiplied by the projected canopy area (widest width x width perpendicular, PCA) of the tree and shrubs and by their respective Kᵦ’s (0.73 for the magnolia and 0.70 for the shrubs). These volumes were summed and applied using the independent woody plant irrigation system.

Daily rainfall was subtracted from each cumulative ET₀ assuming a rooting depth of 30 cm for the turfgrass. For this soil type, this depth would retain only the first 6.25
mm of a rainfall event (Orange County Soil Conservation, USDA 1989). Consecutive
days of rainfall could reduce a cumulative $E_{TO}$ to no lower than minus 0.625 cm.

Turfgrass irrigation occurred beginning at 0500 hour EST. Woody irrigation was
applied beginning at 0700 hour EST. Irrigation was delayed until near sunrise to
minimize the time turfgrass was wet to reduce incidence of disease, and for better
irrigation uniformity due to normally calm or low wind speeds.

Turfgrass was mowed with a push mower (GVC 160, American Honda Motor Co.
Inc., Alpharetta, GA.) equipped with twin blades and a discharge bagging system. The
blades were sharpened regularly. Turfgrass runners extending outside lysimeter
surface areas or into the mulch beds were clipped by hand and included in clipping
harvest. Turf clippings were harvested at each mowing, kept separate by lysimeter, and
quantified after being dried to a constant weight at 65 C. After drying, the clippings
were weighed on a digital scale (PB5001, Mettler-Toledo Inc, Columbus, OH) and
measurements recorded.

Turfgrass was first mowed on 3 December 2009, but not again until 9 April 2010.
From there mowing occurred about every 2 weeks until late May. Thereafter it was
mowed weekly until October, where mowing was reduced to bi-weekly intervals through
November 2010. The turfgrass did not require mowing in December 2010, January,
and most of February 2011. In Late February mowing resumed on monthly basis until
May, and then a bi-weekly schedule until the end of May, which was the completion of
this study.

Turfgrass visual ratings were performed on a monthly basis by three people to
evaluate the aesthetic quality of the turf. Evaluations were made using NTEP, the
National Turfgrass Evaluation Program (Morris and Shearman 2008). Evaluations are made based on a one to nine scale, each level associated with a picture to compare to the actual turf. On this scale, 1 is dead and nine is perfect. Since nine is the theoretical ideal, it is not pictured, and ratings were taken from a comparison with eight pictures (Figure 3-9). Condition of the turf was matched to one of the numbered pictures and the number was assigned for the rating.

Figure 3-9. Turfgrass visual rating guide used to evaluate aesthetic quality of St. Augustine turfgrass. It is based on a one to nine scale, nine being perfect and therefore not shown. Photos courtesy of Michael Dukes.
In order to take into account the effects of all seasons, data collection took place for a period of one full calendar year from 1 June 2010 through 31 May 2011. Visual turf ratings, turf dry mass, and woody growth factors were analyzed. Growth factors for *Viburnum odoratissimum* were collected for projected canopy area (PCA), growth index (GI), and height. Growth factors for *Magnolia grandiflora* were collected for PCA, trunk circumference at 15 cm above the soil, and height. All data collected was compared to the three deficit irrigation levels of 60%, 75%, and 90% of ET$_{O}$.

ET$_{A}$ and ET$_{O}$ were organized into monthly results. Monthly data was grouped up to the point where there was a lull in input and output volumes that allowed for a reasonable calculation of ET$_{A}$ based on lysimeter hysteresis. The next significant input was also taken into account as a break point in the data. Because of lysimeter hysteresis, drainage was still occurring several days after a rain or irrigation event. This drainage was part of that month’s ET$_{A}$ calculation until the next significant rain or irrigation event occurred. Therefore, if the drainage ran over into the next month for a few (less than five) days, it was included in the current month’s calculations. To maintain consistency, the same pattern of going into early days of the next month was used throughout.

The data was analyzed using SAS version 9.2 (SAS, Inc, Cary, NC). Data analysis for water input and turf ratings were conducted using one-way ANOVA. Data analysis for growth data was conducted using repeated measures using split plot and then mean separations using Fisher's protected LSD.
Rainfall for the year of data collection from the onsite weather station was compared to the 14 year average (Figure 4-1) from the Mid-Florida Research and Education Center - Apopka FAWN (Florida Automated Weather Network) site. Total rainfall during the experimental period was not significantly different ($P>0.05$) from the 14 year average. Annual rainfall at the research site was 104.67 cm. The 14 year FAWN average was 119.49 cm. Yet when rainfall was examined on a monthly basis, there were some obvious differences. October 2010 had 0 cm rainfall compared to the average of 8.63 cm, while June rainfall was also 8 cm below normal (Figure 4-1).

Unusual rainfall spikes occurred during the dry season in January and March of 2011. January rainfall total was 12.34 cm compared to an average of 5.34 cm. March rainfall totaled a much higher 20.73 cm when compared to an average of 8.49 cm.

Irrigation input and total water input differed ($P < 0.0001$) among DI (Table 4-1). Total irrigation input was defined as water entering a lysimeter by both turf and woody irrigation systems. Total water input was the sum of total irrigation input and rainfall. For both, the amount of water input into a lysimeter increased with decreasing percentages of deficit irrigation.

<table>
<thead>
<tr>
<th>Deficit irrigation</th>
<th>Total irrigation input</th>
<th>Total water input</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>6,333 a</td>
<td>19,743 a</td>
</tr>
<tr>
<td>75%</td>
<td>9,058 b</td>
<td>22,468 b</td>
</tr>
<tr>
<td>90%</td>
<td>11,857 c</td>
<td>25,267 c</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deficit irrigation</th>
<th>Total irrigation input</th>
<th>Total water input</th>
</tr>
</thead>
<tbody>
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<td>60%</td>
<td>6,333 a</td>
<td>19,743 a</td>
</tr>
<tr>
<td>75%</td>
<td>9,058 b</td>
<td>22,468 b</td>
</tr>
<tr>
<td>90%</td>
<td>11,857 c</td>
<td>25,267 c</td>
</tr>
</tbody>
</table>

Superscript $z$ Percentage of daily ET$_O$ summed to trigger an irrigation event when cumulative ET$_O$ > 1.9 cm. 
Superscript $y$ Total irrigation input is the total amount from woody and turf irrigation systems.
Superscript $x$ Total water input is the total from rainfall, woody irrigation, and turf irrigation systems.
Superscript $w$ Values are the mean of 3 lysimeter replications. Means within a column with the same letter are not different at $P=0.05$ based on Fisher's Protected LSD.
Figure 4-1. Comparison of monthly total rainfall (cm) during the data collection period of 1 June 2010 to 31 May 2011. The onsite weather station was 100 m west of the lysimeter site. The FAWN (Florida Automated Weather Network) average rainfall was based on a 14 yr history of the station within 500 m of the onsite station.

Monthly mean daily $ET_A$, $ET_O$, and $K_L$ are presented below (Table 4-2). The 60% DI had a single-digit low of 0.09 cm $ET_A$ per day in February. $ET_A$ was highest at 0.68 cm per day for the 90% DI in June. The annual average daily value for $ET_O$ was 0.42 cm. $ET_O$ variations also followed seasonal weather patterns, with lower values in the cooler months of November through February.

Monthly $K_L$ values varied among treatments depending on the month ($P<0.05$). Values ranged from a low in February of 0.27 for 60% DI up to a high of 1.49 in March for 90% DI (Figure 4-2). March had no differences among treatments. For June, August, January, and April there were some slight differences among treatments. For June and August the 75% DI was lower than the other two, whereas in January and April, $K_L$ values for the 60% DI were lower than the other two. On the other hand, in
July, September, October, February, and May differences among deficit irrigation treatments were considerable. The 60 and 75% DI were similar in November and December. However, $K_L$ values at 90% DI were much higher for November and December.

Table 4-2. Mean monthly values from 1 June 2010 to 31 May 2011 for daily $ET_O$, daily $ET_A$ (cm) and $K_L$ by irrigation deficit level (DI)

<table>
<thead>
<tr>
<th></th>
<th>60% DI $^z$</th>
<th>75% DI</th>
<th>90% DI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun-10</td>
<td>0.66 $^v$</td>
<td>1.22</td>
<td>0.64</td>
</tr>
<tr>
<td>Jul-10</td>
<td>0.41</td>
<td>0.78</td>
<td>0.34</td>
</tr>
<tr>
<td>Aug-10</td>
<td>0.41</td>
<td>0.86</td>
<td>0.37</td>
</tr>
<tr>
<td>Sep-10</td>
<td>0.41</td>
<td>0.85</td>
<td>0.36</td>
</tr>
<tr>
<td>Oct-10</td>
<td>0.15</td>
<td>0.46</td>
<td>0.34</td>
</tr>
<tr>
<td>Nov-10</td>
<td>0.20</td>
<td>0.71</td>
<td>0.20</td>
</tr>
<tr>
<td>Dec-10</td>
<td>0.15</td>
<td>0.63</td>
<td>0.15</td>
</tr>
<tr>
<td>Jan-11</td>
<td>0.29</td>
<td>1.19</td>
<td>0.33</td>
</tr>
<tr>
<td>Feb-11</td>
<td>0.09</td>
<td>0.27</td>
<td>0.17</td>
</tr>
<tr>
<td>Mar-11</td>
<td>0.62</td>
<td>1.45</td>
<td>0.61</td>
</tr>
<tr>
<td>Apr-11</td>
<td>0.22</td>
<td>0.38</td>
<td>0.29</td>
</tr>
<tr>
<td>May-11</td>
<td>0.36</td>
<td>0.62</td>
<td>0.44</td>
</tr>
<tr>
<td>Averages:</td>
<td>0.33</td>
<td>0.78</td>
<td>0.35</td>
</tr>
</tbody>
</table>

$^z$ Percentage of daily $ET_O$ summed to trigger an irrigation event when cumulative $ET_O > 1.9$ cm.

$^v$ Actual evapotranspiration of a lysimeter with St. Augustine turfgrass, two Viburnum odoratissimum shrubs, and one Magnolia grandiflora, calculated by the difference of water out subtracted from water in.

$^x$ Landscape coefficient calculated as a ratio of $ET_A$ to $ET_O$.

$^w$ Mean monthly values for daily $ET_O$.

$^v$ Values are the mean of 3 lysimeter replications.

$K_L$ values began high in June 2010, and then generally decreased through December. The September 90% DI value was much higher than 60 and 75% DI, while the October 60% DI value was much lower than 75 and 90% DI. 2011 saw more pronounced differences. January and March were much higher than February and April, with peaks upwards of 1.2; whereas dips to 0.6 or lower occurred in February and April. During the months of April to May, $K_L$ showed a slight increase. Differences among treatments were more pronounced in 2010 than during the winter to spring.
seasons of 2011; however oscillations in the $K_L$ values varied much more greatly in the spring.

![Graph showing monthly $K_L$ by treatment during data collection period of 1 June 2010 to 31 May 2011.](image)

**Figure 4-2.** Comparison of monthly $K_L$ by treatment during the data collection period of 1 June 2010 to 31 May 2011. Lines represent different deficit irrigation treatments as a percentage of ET$_{0}$ that was counted toward triggering an irrigation event at $>1.9$ cm. Each point is the mean of 3 lysimeter replicates.

The plots were mowed 24 times over the year (Figure 4-3), with 17 occurring weekly during the peak growing period June through September (Figure 5-1). The plots only needed to be mowed 7 times during the remaining months, of which there was no mowing in December or January. There were no differences among treatments ($P>0.05$) in dry mass harvested from the turfgrass at each mowing. Total mean dry
mass for the 60% DI was lowest at 2.525 kg, while 90% and 75% DI were 2.919 kg and 2.991 kg respectively. However, as could be expected there was an effect of time of year (P<0.0001).

Figure 4-3. Mean dry mass (g) measurements at each mowing for St. Augustine 'Floratam' turfgrass during the first year of deficit irrigation after plant establishment. Means represent nine treatment replicates across deficit irrigation treatments.

Table 4-3. Visual ratings by season for St. Augustine 'Floratam' turfgrass during the first year of deficit irrigation after plant establishment.

<table>
<thead>
<tr>
<th>Deficit irrigation</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>5.61a</td>
</tr>
<tr>
<td>75%</td>
<td>5.95 b</td>
</tr>
<tr>
<td>90%</td>
<td>6.31c</td>
</tr>
</tbody>
</table>

*Percentage of daily ET₀ summed to trigger an irrigation event when cumulative ET₀ > 1.9 cm.


*Values are deficit level means. Treatments with the same letter are not significantly different (α=0.05).

Turfgrass visual ratings varied by DI (Table 4-3; P< 0.0001). Average visual ratings decreased with decreasing DI, and were significantly different among all DI.

Although there were differences in quality ratings, annual mean values for all treatments
were still above the minimum aesthetic threshold of 5.0 established for St. Augustine turfgrass (McCready et al. 2009).

Viburnum growth was similar among treatments \((P>0.05)\) for height, PCA, and canopy volume (GI). All three components of growth increased during the year \((P<0.0001)\). Shrub height increased from 0.7 m to 1.1 m (Figure 4-4), with most increases in height occurring August to September and May to June. Shrub PCA and GI followed similar patterns with peak growth occurring September to October and April to May. Shrub PCA increased from 1.3 m² to 1.8 m² (Figure 4-5). Shrub GI increased from 2.9 to 6.3 m³ (Figure 4-6). Irregularities in both the PCA and GI increases were the result of on-demand pruning to generally maintain the hedge within dimensions of 1 m width north-south and 2 m lengths east-west.

Figure 4-4. Height (m) measurements of *Viburnum odoratissimum* during the first year of deficit irrigation after plant establishment. Means represent 9 treatment replicates across deficit irrigation treatments.
Figure 4-5. Projected Canopy Area (PCA) (m\(^2\)) of *Viburnum odoratissimum* during the first year of deficit irrigation after plant establishment. Means represent 9 treatment replicates across deficit irrigation treatments.

Figure 4-6. Growth Index (GI) (m\(^3\)) of *Viburnum odoratissimum* during the first year of deficit irrigation after plant establishment. Means represent 9 treatment replicates across deficit irrigation treatments.
Increases in magnolia trunk circumference were similar among DI ($P>0.05$), and increased with time ($P<0.0001$). Mean trunk circumference increased from 15.6 cm to 18.5 cm over the year (Figure 4-7). Circumference increased steadily from June to October, then was quiescent until March, when it began to increase through May.

![Graph showing trunk circumference over time](image)

**Figure 4-7.** Trunk circumference (cm) taken 15 cm above soil level of *Magnolia grandiflora* during the first year of deficit irrigation after plant establishment. Means represent 9 treatment replicates across deficit irrigation treatments.

In contrast, both height and PCA of magnolia varied among treatments depending on time of the year ($P<0.05$). Overall annual mean tree height increased from 2.59 m to 3.17 m (Figure 4-8). At the beginning of June the 60% DI trees were 5.3 cm taller than the 90% DI, and 12.3 cm taller than the 75% DI. Late June 2010 through
early April 2011 height of 60% DI trees remained taller than 90% DI trees, which were slightly taller than the 75% DI trees. This was the same February through March. In April and for the rest of the experimental period, the 60% DI trees still remained taller than the other two, while 90% DI trees also remained taller than 75% DI trees.

![Figure 4-8. Mean height (m) measurements of Magnolia grandiflora during the first year of deficit irrigation after plant establishment. Each mean represents 3 tree replications.](image)

At the beginning of June the 90% DI tree had only slightly greater PCA than the 60% DI, both of which were nearly 0.15 m² greater ($P<0.05$) than the 75% DI. For 75% DI magnolias, PCA increased nearly 50% with bud break and branch growth from June to early July (Figure 4-9). The PCA for 75% DI increased the most during this period,
expanding from 0.933 m$^2$ to 1.367 m$^2$, an increase of 0.433 m$^2$. The 90% DI trees had a similar increase of 0.420 m$^2$. The increase for 60% DI trees was nearly half as much at 0.240 m$^2$. All treatments were unchanged through March 2011. Beginning in April 2011, growth increased dramatically with spring bud flush.

Figure 4-9. PCA (m$^2$) measurements of *Magnolia grandiflora* during the first year of deficit irrigation after plant establishment. Each mean represents 3 tree replications.
CHAPTER 5
DISCUSSION

With a relatively warm fall in 2009, the turfgrass had begun to grow after installation in September. Hard freezes occurred each morning from 7 to 10 December 2009, freezing all grass blades. Hard freezes occurred again eight of the first twelve days of January 2010. Woody plants were not injured, but there were no green leaves in the turf grass by 12 January. The rest of January through March remained unusually cold, with several more freezes. Bud break on the viburnum (Beeson 2004) and magnolias (Beeson 1991) were several weeks later than normal. Turfgrass exhibited signs of life in late March 2010. Neither the viburnum nor the magnolia had exhibited any shoot growth since transplanting in September 2009 until this point due to normal post-transplanting allocation to root growth (Scheiber et al. 2007) and onset of winter dormancy. Magnolia shoot growth did not begin until mid-April 2010.

Despite the unusually cold winter 2009-2010, there were no woody plant fatalities during the one year period of this experiment. Turfgrass disease and pest management was required to maintain healthy plots during the year. Gaps in fine tuning these requirements, combined with the unusually cold winter, followed by a hot dry spring resulted in the need for the replacement of some turfgrass. For the remaining ten months no problems were experienced, even though rainfall was frequently below average. Irrigation at all DI levels provided acceptable growth for all plant material in the mixed landscape.

Although annual rainfall was similar to the 14 year average, monthly deviations greatly influence irrigation needs and leaching below the root systems. With no rainfall in October 2010, 100% of water needs were provided by irrigation. At this time, the
effect of the different DI levels became evident. The 60% DI required an average of 4.29 cm of supplemental irrigation in October, while both the 75% and 90% DI required over 9 cm of supplemental irrigation for that period. If the 14 year average rainfall of 8.63 cm had occurred, then almost no supplemental irrigation would have been needed. If historical rainfall data had been used (Haley et al. 2007) instead of real time weather data (McCready et al. 2009) then the turf plots would have been severely under-watered. These findings underscore the need for real time weather data when calculating landscape water needs.

Figure 5-1. Seasonal shoot and root growth pattern of warm-season turfgrass (Turgeon 2002). Each tick on the horizontal represents one month.

Turfgrass growth is moderated by temperature, and typically occurs within a range of 40 to 105 F (Beard 1989). Therefore, turfgrass growth cycles follow seasonal temperatures. St. Augustine is a warm season C4 turfgrass. Warm season growth cycles increase in the March/April range and decline in the September/October range (Figure 5-1). Warm season grasses typically experience maximum growth when
daytime temperatures are between 80 and 95°F (Christians 2011). Even when rainfall is high during periods of low temperatures (Figure 4-1), turfgrass growth does not respond with an increase in rate (Figure 4-3). Based on this response, irrigation should follow the same seasonal conditions that moderate turfgrass growth.

January and March $K_L$ values were outliers. These values were disproportionately higher than seasonal trends set October through December, and February. January and March both had higher than average rainfall (Figure 4-1). Low rainfall in November and December resulted in conditions that allowed the soil to dehydrate. Apopka fine sand is somewhat coarse and water can percolate through quickly if the soil has been well-irrigated or there has been consistent rainfall. The water holding capacity of soil that is allowed to dry out is much greater, and would take much longer to reach field capacity and begin draining (Kramer and Boyer 1995). This would cause the dehydrated soil to retain more water during rain and irrigation, reducing drainage and providing more plant available water. The reduced drainage would make the $ET_A$ appear higher, since $ET_A$ was calculated as the difference between water input into a lysimeter and the volume recovered from drainage. $ET_O$ during these months was also lower due low sun angles and cooler temperatures. Since $K_L$ is calculated as a ratio of $ET_A/ET_O$ this would cause higher values for $K_L$.

The high $K_L$ value for the September 90% DI treatment resulted from a high average daily $ET_A$ value for 90% DI in September of 0.50 cm compared to 0.41 cm for 60% DI and 0.36 cm for 75% (Table 4-2). A sharp decline in mean turfgrass dry mass harvest also occurred during this period (Figure 4-3). Mean dry mass harvest for August were 843 g for 60% DI, 933 g for 75% DI, and 1030 g for 90% DI; compared to
means for September that were 275 g for 60% DI, 421 g for 75% DI, and 402 g for 90% DI. In September warm season turf grass is nearing the end of the peak growing season (Figure 5-1), and growth slows. Visual turfgrass ratings were higher overall for the 90% DI, but there was no time x DI interaction (P>0.05). Therefore, there is no statistical evidence that factors evolving from dry mass and visual ratings could provide an explanation for higher ET\textsubscript{A} in September.

The opposite effect occurred in October with K\textsubscript{L} for 60% DI. The K\textsubscript{L} value was much lower than 75% and 90% DI because of low ET\textsubscript{A}. Daily average ET\textsubscript{A} for October was 0.15 cm for 60% DI compared to 0.34 cm for 75% DI and 0.29 cm for 90% DI (Table 4-2). Turf dry mass for October was low for all treatments with 60% DI at 71 g, 113 g for 75% DI, and 99 g for 90% DI (Figure 4-3). Mean turf visual ratings were lower overall for the 60% DI. Again there is also no statistical evidence that factors evolving from dry mass and visual ratings could provide an explanation for the lower ET\textsubscript{A} in October.

Between April and September, turfgrass dry mass measurements had peaks just after periods of heavy rainfall (Figure 4-1), and dry mass harvest was generally greater during these months (Figure 4-3). However, when rainfall was higher than average in January and March, the turfgrass did not respond with increased dry mass measurements. This response follows the growth pattern of warm season turfgrass (Figure 5-1). This response also indicates that residential landscape irrigation applied above turf water needs is wasted (Haley et al. 2007), because turf water needs are typically very low in January and March (Table 4-2).
With equivalent rainfall among treatments (Figure 4-1), differences in growth among DI can be attributed to the effects of the irrigation frequency. The 60% DI turfgrass had the lowest dry mass for the year, while the 75% and 90% DI both had about 400 more grams more dry mass for the period. Extra irrigation given to the 75% and 90% DI plots encouraged unnecessary growth, to gain only modest increases in visual rating scores (Table 4-3), at a cost of nearly twice the irrigation (Table 4-1) to meet the increased DI.

Turf visual ratings varied by DI level, with ratings for the 60% DI declining below that of the other two levels. Even then the average score was 5.61 (Table 4-3). This was still above the minimally acceptable level of 5.0 established for St. Augustine turfgrass assessments in a residential setting (McCready et al. 2009). A score of 4.3 in May for the 60% DI was the only value below this level. Considering the scores overall, the ratings achieved a high of 6.6. With a potential maximum of 9.0 on the scale that was used, ratings generally remained just above acceptable. It is possible that the ratings could improve if the system was observed for a longer period of time, giving the turf more time to produce the dense stoloniferous spread within the turf area that St. Augustine is known for.

Woody plants had consistent growth throughout the year, but for the most part did not vary among treatments with the only exceptions being tree height (Figure 4-8) and tree PCA (Figure 4-9). For these variables, tree PCA increase from June to May was greater for 60% DI at 0.32 m², than the 0.25 m² for 75% DI; and tree height increase was equivalent for 60 and 90% DI at 0.46 m², and higher than the 0.40 m² increase for 75% DI. Both variables demonstrated responses where less irrigation
resulted in greater tree growth over the year. The physiological reaction to water stress of many woody plants is to increase root growth and slow top growth. Then when water becomes available, they can produce faster top growth (Gilman 1990). Those irrigated more frequently had more top growth (Scheiber and Beeson 2007), and this was also shown in turfgrass (Sinclair et al. 2011). At lowest DI, plants were likely encouraged to allocate more resources extending roots to find available water.

Root mass was not quantified in this experiment. But the behavior described could be attributed to higher root mass. The concept of deep and infrequent watering encouraging deep root penetration was established by Sachs et al. (1975). When established landscape plants were trench irrigated with >8 cm of water, the soil profile was saturated several feet deep. Although these plots were irrigated much less frequently, they still maintained acceptable aesthetic levels. Similar results are reported here for the 60% DI. It appears magnolias in the 60% DI were prepared to take better advantage of available water than 75% DI, producing more top growth over the year. When you combine the increased water holding capacity of dehydrated soil with the possibility of increased root growth from water stressed plants, you have the opportunity for periods of modestly greater shoot and canopy growth exemplified by the 60% DI in this experiment. The apparent adaptability of woody plants and turfgrasses to stress levels induced by water budgeting could lead to more work that would determine how to encourage this kind of behavior in the landscape. It is possible that these differences in top growth could expand over time, and data for a longer period could prove useful.
CHAPTER 6
CONCLUSION

Turfgrass irrigation based on ET₀ required less frequent mowing than is typical within the landscape maintenance industry. Typically, a lawn service will contract with the homeowner for weekly mowing March/April through August/September; and then bi-weekly mowing for the remaining winter months. Some clients insist on weekly visits year round (personal experience, S. Simpson). This typically results in a lawn being mowed 39 to 45 times or more per year. For this study, mowing totaled 24 occurrences annually, needing bi-weekly or less mowing during the dry spring months, needing to be mowed only 7 times in the months where warm season turf growth is minimal (Figure 5-1), and with no mowing in December, January, and most of February. This is nearly a 50% reduction in the need to run the mower when compared to typical industry practices.

Warm season turfgrass simply does not grow in the cold temperatures of winter (Christians 2011). Spring in Florida is usually a period of low rainfall (Figure 4-1) and rising temperatures. Often during the summer, there are extended periods with no rainfall. Extensive supplemental irrigation and spring fertilization take place during these periods. These practices work together to stimulate unnecessary spring growth. If irrigation were reduced through the use of real time ET data and landscape coefficients, not only would there be a tremendous savings in water use, but also a reduction in fertilizer application, the potential for reduced groundwater contamination, and the environmental benefits of reduced mowing. Reduced maintenance requirements associated with less frequent irrigation has more potential than simply cost savings to the homeowner, but also to reduce fuel consumption and subsequent
emissions. Since one hour of push mower use equals 50 miles in a typical car (EPA 1991), potential emissions savings statewide become as big a factor as water savings.

\( \text{ET}_A \) levels demonstrated increasing values as irrigation levels increased (Table 4-2). Higher \( \text{ET}_A \) values for the turfgrass and plant material indicate a propensity for the plant material to use more water as it becomes available. Since all plant material remained above minimum aesthetic rating requirements (Table 4-3), this indicates that the turfgrass and woody plants adapted to each DI while demonstrating the acceptable aesthetics deemed necessary for residential landscapes. Based on these findings, we could irrigate a mixed landscape at 60% DI and still have turf that looks as good as if we had irrigated at 90% DI. This adaptability is crucial to the success of a landscape facing water stress, and should be encouraged through the manipulation of cultural practices including irrigation frequency.

Aside from the outliers discussed above, \( K_L \) results closely followed seasonal demands and indicated the potential for usefulness in water conservation when used to schedule mixed landscape irrigation based only on turf water needs. ET based irrigation controllers could use these \( K_L \) values to accurately correct \( \text{ET}_O \) and provide irrigation frequently enough to maintain acceptable aesthetic levels in residential landscapes and reduce unnecessary watering. Other studies also concluded that St. Augustine turfgrass could be irrigated and maintained at 60% \( \text{ET}_O \) (Dukes 2007) using soil moisture sensors and ET controllers. The results presented here confirm that not only is irrigation possible at the deficit levels tested, but suggest lower deficits may also demonstrate acceptable aesthetic levels. Weather data and \( \text{ET}_A \) observations over a
longer period may be useful when testing lower deficit levels in order to give the turfgrass time to spread and fully extend its roots.

Given the variation in climate and rainfall, data collection over several years would be useful. More exploration into the physiology of root response of turf and woody reactions to stress and potential avenues into how to encourage those stress adaptations could also provide insight into methods of conditioning these plants to handle less frequent irrigation. The effects of soil water holding capacity of dry soils on large scale lysimetry used in deficit irrigation research must also be further investigated so that these effects can be accounted for in $ET_A$ observations and subsequent $K_L$ calculation.
LIST OF REFERENCES


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BIOGRAPHICAL SKETCH

Scott Simpson received his Master of Science degree from the University of Florida in spring 2012. His major was environmental horticulture. Previously in 1992, he received his Bachelor of Arts degree from University of Central Florida. Scott was required to return to community college to complete biology I and II and chemistry I and II prerequisites in fall 2007. In fall 2008, he was admitted to University of Florida where he pursued his post baccalaureate studies in landscape management. Upon completion of these requirements, he was accepted into the masters program in fall 2009. During this time, he also started and operated a landscape management business, eventually expanding into landscape design and installation. Scott now specializes in the retrofit of existing landscapes with native, Florida friendly, and water wise plant material.