

SALT AND DROUGHT TOLERANCE OF FOUR ORNAMENTAL GRASSES

By

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To my father for his unwavering pride and support

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Abstract of Thesis Presented to the Graduate School  
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SALT AND DROUGHT TOLERANCE OF FOUR ORNAMENTAL GRASSES

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Water use is the most important environmental issue facing the horticulture industry. As a result, many water management districts are recommending native plants for their putative low-water requirements. Numerous textbooks and trade journals claim native plants use less water than non-natives; however, previous research found no difference in water use efficiency in the field between native and non-native species. Furthermore, recommendations of ornamental grasses for use as low-maintenance and low-water requiring landscape plants have recently escalated.

This study evaluated non-native *Miscanthus sinensis* 'Adagio' and the native *Eragrostis spectabilis* for irrigation requirements and drought response in a landscape setting. To simulate maximum stress, both species were planted into field plots in an open-sided, clear polyethylene covered shelter. Each species was irrigated on alternating days at 0L, 0.25L, 0.5L, or 0.75L for a 90 day period. Growth index and height were recorded at biweekly intervals, and final shoot and root dry masses were taken at completion of the study. Significant treatment and species effects were found for height, growth index, shoot dry weight, and biomass. Plants receiving 0.75L of irrigation had the greatest growth and non-irrigated plants grew significantly less. Comparisons between species found growth was greatest among *Eragrostis spectabilis* plants for all

parameters. Salt tolerant landscape plants are important to ornamental growers, landscapers and residents in coastal communities. Ornamental grasses are frequently recommended for low-maintenance landscape situations and may be candidates for coastal plantings once they are evaluated for their salt spray tolerance. Maiden grass (*Miscanthus sinensis* Anderss. ‘Gracillimus’) and fountain grass (*Pennisetum alopecuroides* (L.) Spreng. ‘Hamelin’) were subjected to four treatments (100% seawater, 50% seawater, 25% seawater, or 100% deionized water) to determine salt spray tolerance. As seawater concentration increased, root, shoot, whole plant biomass gain, height, flower number, and visual quality decreased for both taxa; however, fountain grass appears to be slightly more tolerant of salt spray than maiden grass.

## CHAPTER 1 INTRODUCTION

Drought and corresponding water restrictions are forcing landscapers and consumers to seek alternative irrigation practices and plants that require minimal irrigation for survival (Knox, 1990). Ornamental grasses are generally regarded as problem free low maintenance plants (Dana, 2002), and are recommended for their putative low-water requirements. In addition to water concerns, increasing development along Florida's coastlines has created a stronger market for plants suitable for a seaside environment. Plants that can meet needs of a typical Floridian landscape must not only withstand drought, heat and humidity, but frequently must be salt tolerant as well.

### **Drought Tolerance**

A large body of research exists on relationships between grasses and water use (Blicker, Olson, and Wraith, 2003; Bolger, Rivelli, and Garden 2005; Greco and Cavagnaro, 2002; Guenni, Marin, and Baruch, 2002; Mohsenzadeh, Malboobi, Razavi, and Farrahi-Ashtiani, 2006), yet research quantifying water requirements of ornamental grasses for establishment and/or maintenance in residential landscapes is limited (Zollinger, Kjelgren, Cerny-Koenig, Kopp, and Koenig, 2006). Many water management districts have recommended native plants to their consumers (SFWMD, 2001; SWFWMD, 2003) under the premise that Florida native plants use less water than non-native plants (Haehle, 2004; Hostetler, Klowden, Miller, and Youngentob, 2003; SFWMD, 2001). Limited research has been done to substantiate the assumption that native plants use less water than non-native plants. Kissel, Wilson, Bannister, and Mark (1987) examined water relations of four exotic and three native New Zealand species and found no overall difference existed between adaptation mechanisms of native and exotic species. Glenn et al. (1998) found no difference in water use efficiency between two native and

two invasive riparian species from the Colorado River delta. However, Blicher et al. (2003) found that native *Pseudoroegneria spicata* (Scribn. And Smith) and *Pascopyrum smithii* (Rybd.) produced more biomass under drought conditions than invasive *Centaurea maculosa* (Lam). A study in Australia of seven native and three introduced perennial grass species subjected grasses to continuous drought and found mixed results among performances of native and exotic species (Bolger et al., 2005). Drought resistance may be less a function of a plant's status as native or non-native, and more that of its individual physiology and natural range (Chapman and Auge, 1994). In addition, ecology of cultivated landscapes is not the same as natural environments. Plant selection should take into account individual site criteria and plants' cultural requirements in addition to its native or non-native status (Anella, 2000; Knox, 1990).

### **Salt Tolerance**

As of 2003, 153 million people, 53% of the United States population, lived in the nation's 673 coastal counties (Crossett, Culliton, Wiley, and Goodspeed, 2005). As development increases landscape plants that tolerate coastal conditions become critically important to the ornamental landscape industry.

Researchers have documented injury from airborne salts to plants growing near the coast (Edwards and Holmes, 1968; Karschon, 1964; Malloch, 1972). Exposure to water with high salt content reduces or inhibits plant growth (Belligno, Cutore, Di Leo, Sardo, and Brancato, 2002a; Belligno, LaLoggia, Sambuco, Sardo, and Brancato, 2002b; Marcum, 2001; Qian, Wilhelm, and Marcum, 2001). Much of the research done in salinity tolerance concerns saline soil or saline irrigation (Alshammary, Qian, and Wallner, 2003; Belligno et al., 2002a, 2002b; Gulzar, Khan, and Ungar, 2003; Hunter and Wu, 2005; Marcum and Murdoch, 1994; Marcum, Pessarakli, and Kopec, 2005), but little research has focused on exposure to salt spray under non-saline irrigation conditions. It is well documented that plants are often more sensitive to saline spray than to salt

applied at the root zone (Benes, Aragues, Grattan, and Austin, 1996; Bernstein and Francois, 1975; Grattan, Mass, and Ogata, 1981; Grattan, Royo, and Aragues, 1994; Westcot and Ayers, 1984). In addition, much of the research done assesses survival rates of plants under saline conditions, but few studies consider the aesthetic value of the plants after foliage is exposed to water with high concentrations of salt (Marcum et al., 2005). For landscape plantings to be successful, they must not only survive but meet high aesthetic standards. Many publications list suitable salt-tolerant ornamental landscape plants, but little quantified information exists for the salt tolerance of individual ornamental grass species.

### **Objectives**

The objectives of this study were to evaluate two ornamental grasses for drought response in a landscape setting and to determine effects of salt spray on appearance, flower number, growth and mortality of two ornamental grasses.

## CHAPTER 2 LITERATURE REVIEW

Water availability is the primary limiting factor for ornamental landscapes (Chapman and Auge, 1994; Scheiber and Beeson, 2006). Drought and corresponding water restrictions are forcing landscapers and consumers to look for alternative irrigation practices and plants that will survive low-water conditions. Ornamental grasses are generally regarded as problem free low maintenance plants (Dana, 2002), and are commonly recommended to the public for their putative low-water requirements in landscapes. Most grasses suited for Florida are C<sub>4</sub> plants adapted to withstand tropical weather conditions and low-water environments (Taiz and Zeiger, 2002). A large body of research exists on relationships between grasses and water use, yet research quantifying water requirements of ornamental grasses for establishment and/or maintenance in residential landscapes is limited (Zollinger et al., 2006). Studies comparing the water usage of native Florida grasses and non-native grasses have not been conducted. In addition to water concerns, increasing development along Florida's coastlines has created a stronger market for plants suitable for a seaside environment. Plants that can meet the needs of a typical Florida landscape must not only withstand drought, heat and humidity, but frequently must be salt tolerant as well.

### **Drought Tolerance and Ornamental Grasses**

#### **Need for Drought-Tolerant Plants**

Landscape consumption of potable water has been a source of scrutiny and has resulted in water restrictions across the United States. According to the Environmental Protection Agency irrigation accounts for 81% of fresh water consumption in the U.S (Environmental Protection Agency, 1995). Increasingly, counties and water management districts in Florida are implementing partial bans on outdoor water use, including landscape irrigation (SWFWMD,

2003). With water becoming less available for non-essential uses such as landscape irrigation, demand for low-water use landscapes is increasing. Ornamental plants serve an aesthetic as well as functional role, so selected plants should be able to withstand drought and still be visually appealing in landscapes. As yet, water requirements and drought responses for ornamental plants are not yet well defined for a large number of species, especially herbaceous perennials (Zollinger et al., 2006). In many cases, drought tolerance assessment for grasses is based on forage yield (Bolger et al., 2005, Greco and Cavagnaro, 2002; Guenni et al., 2002), or physiological assessment of turfgrass cultivars (Huang and Gao, 1999; Perdomo, Murphy, and Berkowitz, 1996). Similar to yield measurements of agricultural and forage crops, success of ornamental landscapes can be determined by biomass accumulation and growth indices. However, plants in landscapes serve a different purpose than agronomic crops, and subjective criteria such as aesthetic appeal are often the benchmark for performance (Kjelgren, Rupp, and Kjelgren, 2000).

### **Native/Non-native Plant Issue**

#### **Relevance**

Many Florida water management districts have recommended native plants to their consumers (SFWMD, 2001; SWFWMD, 2003) under the premise that Florida native plants use less water than non-native plants (Haehle, 2004; Hostetler et al., 2003; SFWMD, 2001). Furthermore, species categorized as invasive and hazardous to Florida's ecology have been outlawed (FL Statute 581.185). The Florida Exotic Pest Plant Council has defined the following terms to describe the role of plants in Florida's ecosystem (FLEPPC, 2006): *Exotic* – a species introduced to Florida, purposefully or accidentally, from a natural range outside of Florida; *Native* – a species whose natural range included Florida at the time of European contact (1500AD); *Invasive exotic* – an exotic that not only has naturalized but is expanding on its own

in Florida plant communities. Plants found to be overly aggressive by displacing native plants and animals have been labeled as invasive, and plants existing in Florida at the time of European contact have become native. These definitions have led to research into roles of invasive and native plants in ecosystems and potential physiological traits that make invasive plants prolific and native plants well-adapted to Florida. However, little research has been done to substantiate assumptions that native plants use less water than non-native plants, that natives are better for ecosystems in residential settings, or that native plants generally perform better with less maintenance than non-natives. In addition, cultivated residential landscapes are significantly altered by human use and development, and bear little resemblance to native landscapes (Knox, 1990).

Kissel et al. (1987) examined water relations of four exotic and three native New Zealand species and found that no overall difference existed between adaptation mechanisms of native and exotic species. Glenn et al. (1998) found no difference in water use efficiency between two native and two invasive riparian species from the Colorado River delta. Blicher et al. (2003) found native *Pseudoroegneria spicata* (Scribn. and Smith) and *Pascopyrum smithii* (Rybd.) produced more biomass under drought conditions than invasive *Centaurea maculosa* (Lam.), refuting the hypothesis that greater water use efficiency is key to successes of invasive species in an ecosystem. A study in Australia of seven native and three introduced perennial grass species subjected grasses to continuous drought and found native species survived for both the longest and shortest periods of time, with exotic species falling intermediate (Bolger et al., 2005). Drought resistance may be less a function of a plant's status as native or non-native, and more that of its individual physiology and natural range (Chapman and Auge, 1994). In addition, cultivated landscapes are not the same as natural environments, and plant selection should take

into account site criteria and an individual plant's cultural requirements in addition to its native or non-native status (Anella, 2000; Knox, 1990). Consequently, research is needed to determine which ornamental grass species are truly suited for low-water cultivated landscapes, and which of those species are able to withstand drought conditions while maintaining landscape value through aesthetic appeal.

### **Economic importance**

A recent trend in residential landscaping has been to eliminate all non-native plants in favor of natives that are championed as being not only more water efficient, but better for the local ecology (Haehle, 2004; Hostetler et al., 2003; SWFWMD 2001). Relative sales of native and exotic plants in Florida are as yet undetermined due to a lack of tracking of individual plant sales. More information is needed to determine economic impacts of eliminating non-native plants from the nursery industry (Fox, Gordon, Dusky, Tyson, and Stocker, 2004).

### **Drought Stress Physiology**

Plants adapt to water stress in one of three ways. First is an ability to maintain tissue hydration under water stress via two strategies. 'Water savers' use water conservatively so that not all soil moisture is depleted. 'Water spenders' use water aggressively, often to the deprivation of surrounding plants. Second is an ability of a plant to function while dehydrated, and includes several acclimation strategies discussed below. The third level of adaptation is 'drought escape', in which plants complete their life cycles during wet seasons, thereby completely avoiding situations of water stress (Taiz and Zeiger, 2002). For plants that cannot escape drought, they must adapt to survive. Non-succulent plants are unable to physically store large quantities of water in their tissues, and so they must undergo alterations to physiological processes to conserve water. These plants have a complex, often interrelated system of managing water deficit. A standard sequence of physiological events occurs when water stress

develops gradually (Hsiao, 1973). This sequence begins with the response most sensitive to water deficit and progresses to those processes that respond to only the most severe water deficit.

First in this sequence, and most sensitive to reduced water, is cellular growth. A decrease in water potential outside of a cell results in a perceptible decrease in cell growth and therefore a decrease in growth of roots and shoots (Neumann, VanVolkenburgh, and Cleland, 1988; Sakurai and Kuraishi, 1988). This adaptation is likely the cause for an often-observed water stress response of an overall decrease in plant growth and biomass. Water stress can reduce biomass in some species of grasses by 60% (Fernandez, Wang, and Reynolds, 2002). Inhibition of cell expansion is followed by a reduction in cell wall and protein biosynthesis, enzyme activity, and cell division (Salisbury and Ross, 1992). These responses cumulatively result in a decrease of leaf area. Water stress decreases cell expansion, which slows leaf expansion, which in turn reduces transpiring leaf area and thereby conserves water supply over a longer time period. Drought studies on herbaceous species have repeatedly shown that leaf expansion and morphological and allocation variables are more sensitive to water stress than leaf conductance and instantaneous carbon gain (Kalapos, van Den Boogard, and Lambers, 1996; Kramer and Boyer, 1996; Sadras and Milroy, 1996). Because of this, a measure of the leaf area is the main determinant of maximum relative growth rate, rather than net carbon assimilation rate (Hunt and Cornelissen, 1997). Some species of plants respond to water stress by allocating proportionally more biomass to roots and less to leaves and by producing leaves of smaller area:weight ratio than those under well-watered conditions (Fernandez et al., 2002). However, if plants become stressed for water after a certain leaf area has developed, leaves will simply senesce and fall off in response to increased ethylene synthesis (Taiz and Zeiger, 2002).

Second in response to water deficit is root extension. Root:shoot biomass ratio is partially maintained by a balance between root water uptake and shoot photosynthesis. Shoots will grow until water uptake by roots becomes limiting, and roots will grow until assimilates provided by shoots are limiting. When water deficit occurs, the top few inches of soil begin to dry, so roots grow into soil zones that still retain water. As root tips grow, assimilates must be allocated to them. However, when plants are in the reproductive stage, photosynthates go to the developing fruits first, which may explain why plants are more susceptible to drought during reproduction (Taiz and Zeiger, 2002).

When water deficit continues to increase, stomatal closure occurs. This response reduces evaporation from existing leaf area, which is especially useful when stress develops quickly or when a plant has achieved its full leaf area before stress occurs, making reduced leaf expansion a useless stress response. Stomata may close passively due to a loss in guard cell turgor from water evaporation to the atmosphere, or actively when leaves or roots are dehydrated and a reduction in solute content of guard cells causes closure (Taiz and Zeiger, 2002). Chemical signals from roots may also affect stomatal responses to water stress (Bohnert, Nelson, and Jensen, 1995; Davies, Wilkinson, and Loveys, 2002). Eventually, photosynthesis begins to decrease as mesophyll cells become dehydrated and metabolism is impaired. Translocation of assimilates is unaffected until late in the stress period to allow plants to utilize their reserves when necessary (Taiz and Zeiger, 2002). However, at the highest levels of water stress, respiration, translocation, and CO<sub>2</sub> assimilation drop to levels near zero (Salisbury and Ross, 1992).

Most plants undergo some variation on water deficit responses. All plants have genetic encoding for stress perception, signaling and response, and a wide variety of species express a

common set of genes and similar proteins when stressed (Flowers and Flowers, 2002). No evidence has been found to date that distinguishes native from non-native plants where water stress responses are concerned.

Some herbaceous ornamentals adapt to drought through drought avoidance mechanisms such as leaf senescence when water is limiting (Zollinger et al., 2006). Reduction in dry mass has been found to be a common experimental result of drought stress. Guenni et al. (2002) found a reduction in dry mass for *Brachiaria brizantha* (A. Rich.) Stapf, an African neotropical grass, when exposed to moderate drought stress. Drought-stressed *Gaillardia aristata* Pursh showed a reduced dry mass of 50% and 84%, and dry mass of *Leucanthemum ×superbum* (Bergmans ex J.Ingram) Soreng & E.A.Cope was reduced by 47% and 99% when exposed to 2- and 4-week irrigation intervals (Zollinger et al., 2006). Greco and Cavagnaro (2002) subjected three varieties of the native Argentinean grass *Trichloris crinita* (Laq.) Parodi to drought conditions, all of which showed significantly reduced total dry mass as compared to controls receiving optimal irrigation.

## **Salt Tolerance and Ornamental Grasses**

### **Need for Salt Tolerant Plants**

As of 2003, 153 million people, or 53% of the United States population, lived in the nation's 673 coastal counties (Crossett et al., 2005). As development and growth of coastal areas increase, landscape plants that can tolerate harsh coastal conditions become critically important to the ornamental landscape industry. Observations have been made of both naturally occurring coastal vegetation and installed seaside landscape plants being injured by airborne salts (Edwards and Holmes, 1968; Karschon, 1964; Malloch, 1972). Marcum (1999) and Belligno et al., (2002a) observed increased leaf firing, defined as the percent of dead or chlorotic tissue, with increasing salinity of irrigation water. Irrigation water with high salt content has been found to reduce or

inhibit plant growth (Marcum 2001; Qian et al.,2001). Ashraf, McNeilly, and Bradshaw, (1986) found that in both control and selected lines of four grass species, dry biomass and tiller number were greatly reduced with increasing exposure to salinity. Dry and fresh biomasses of forage grasses have been found to decrease with increasing percentages of seawater in irrigation applications (Belligno et al., 2002a, 2002b). Many publications list suitable salt-tolerant ornamental landscape plants, but little quantified information exists for salt tolerance of individual ornamental grass species.

The majority of research done in salinity tolerance concerns saline soil or saline irrigation. Hunter and Wu (2005) tested five ornamental grass species for tolerance to saline irrigation water, and found no significant difference between control and saline treatments in four of five species. Glenn et al. (1998) subjected six native and non-native riparian species to varying levels of soil salinity and found a wide variety of tolerance levels among species. Four turfgrass species grown in saline hydroponic solution or under saline irrigation were found to have a 50% reduction in root and shoot growth at varying salinity levels (Alshammary et al., 2004). Gulzar et al. (2003) found reduced growth and dry mass with increasing soil and irrigation salinity for the halophytic coastal salt marsh grass *Urochondra setulosa* (Trin.). Marcum (1999) exposed a wide variety of turfgrass and forage genera to saline solution culture to test salinity tolerance of Chloridoideae. Overhead saline irrigation was found to reduce yield through foliar injury in pepper plants (Maas, Clark, and Francois, 1982). Westcot and Ayers (1984) examined effects of saline irrigation through reclaimed wastewater and found high levels of salinity were detrimental to yield of several food crops.

Despite the fact that plants are often more sensitive to saline spray than to salt applied at the root zone, relatively little research examines exposure to salt spray under non-saline

irrigation conditions. Benes et al. (1996) and Grattan et al. (1981, 1994) found that saline spray exposure resulted in a greater biomass reduction than soil salinity in barley. Bernstein and Francois (1975) found that a reduction in yield of alfalfa was greater under saline irrigation than under saline soil conditions. In addition, much of the research done assessed survival rates of ornamental grasses under saline conditions, but few studies considered aesthetic value of plants after foliage was exposed to water with high concentrations of NaCl (Marcum et al., 2005). For landscape plantings to be successful, they must not only survive but meet high aesthetic standards.

### **Physiological and Adaptive Mechanisms**

Salt tolerance is a complex trait regulated by a number of genes (Barkla, VeraEstrella, and Pantoja, 1999; Flowers, Hajibagheri, and Clipson, 1986; Gorham, 1992). In crop plants, salt tolerance varies widely among species and varieties (Francois and Mass, 1993; Maas, 1990). Plants that are able to complete their life cycles under saline conditions with enhanced growth at moderate salinity, and are able to survive up to  $340 \text{ mol m}^{-3}$  NaCl are defined as halophytes (Khan, Unger, and Showalter, 1999). Research has been conducted to investigate how halophytes are able to adapt to highly saline conditions, largely in an effort to use their adaptive traits to introduce their adaptive mechanisms into non-halophytic plants (Flowers and Flowers, 2002). Salt stress can both reduce (Glenn et al., 1998; Greenway and Munns, 1980) and enhance (Hester, Mendelssohn, and McKee, 2001) growth rates of both halophytic and non-halophytic (glycophytic) plants. In addition, low to moderate salt stress has been found to increase root biomass (Ben-Asher and Silberbush, 1992; Rozema and Visser, 1981; Waisel, 1985) and accelerate reproductive growth stages (Dhingra and Varghese, 1997; Grieve, Francois, and Maas, 1994; Munns and Rawson, 1999). Grattan et al. (1994) found an increase in overall proportion of total shoot biomass devoted to flowering in barley. In halophytic plants, biomass attributes may

not be affected by salt tolerance, because they have physiological and/or morphological mechanisms that would allow for salt resistance, such as selective ion exclusion and secretion (Hester et al., 2001; Hunter and Wu, 2005).

Salt tolerance requires compartmentalization and compatible solutes (Hall, Harvey, and Flowers, 1978; Harvey, Hall, Flowers, and Kent, 1981; Larher, Jolivet, Briens, and Goas, 1982), regulation of transpiration (Clipson and Flowers, 1987), control of leakage across the apoplast (Yeo and Flowers, 1986), and tolerance of low potassium to sodium ratios within the cell (Flowers and Dalmond, 1992). Some plants have salt glands which help maintain an acceptable salt level in the leaves (Flowers and Yeo, 1986). It has been suggested that a faster growth rate in halophytic plants allows for more mature tissue to be available for storage of excess salts away from new growth areas (Hunter and Wu, 2005). However, it is widely held that the symptoms of salt injury are from either osmotic effects or from the toxicity of saline ions (Hunter and Wu, 2005), although the role of each is less well understood (Bernstein and Hayward, 1958). Greenway and Munns (1980) suggested that compartmentalization of saline ions is the most important criteria for achieving salt tolerance in many higher plants.

## **Plants**

### ***Pennisetum alopecuroides***

*Pennisetum alopecuroides* (L.) Spreng., chinese fountain grass, is a member of Poaceae, Subfamily Panicoideae, Tribe Paniceae (USDA, NRCS 2006). It is a C4 grassland plant, native to Asia and Australia, is best suited for USDA cold hardiness zones 5–9, and is used in cultivation as a specimen plant. *Pennisetum alopecuroides* grows best in full sun in evenly moist, well-drained soils, but can adapt to various soil types. It is readily propagated by division, and is moderately self-sowing by seed (Darke, 1999). *Pennisetum alopecuroides* is a fine-textured, mounding perennial ornamental grass that reaches to about 1m tall by 1m wide, with medium-

green thin (0.25” wide) foliage which radiates from basal crowns. Inflorescences are lime green to violet 12.7cm (5 inch) long foxtail-like spikes, borne above the foliage in late summer (Darke, 1999).

*Pennisetum alopecuroides* ‘Hamelin’ is a compact, mounding form of the species which grows up to 50.4 cm (20 inches) tall by 91 cm (36 inches) wide. Foliage is medium green, and flowers are cream-colored. Hardy in USDA zones 6a–8a, fall foliage turns yellow and persists through winter. *Pennisetum alopecuroides* ‘Hamelin’ is widely sold in the nursery trade due to its compact habit and early flowering time that begins about two weeks earlier than the species (Darke, 1999).

### ***Miscanthus sinensis***

*Miscanthus sinensis* Anders., also known as chinese silver grass, eulalia, or maiden grass, is a member of Poaceae, Subfamily Panicoideae, Tribe Andropogonae. It is a C4 plant native to tropical and temperate Asia, and is naturalized throughout the Americas, including most of the United States (USDA, NRCS 2006). It grows best in full sun, and can adapt to various soil textures and moisture levels. It is considered heat- and drought-tolerant, and is hardy in USDA zones 5–9. *Miscanthus sinensis* is a medium to large perennial ornamental grass (size is dependent on cultivar) reaching anywhere from 0.9–4.5m (3–15 feet) tall by 0.6–1.8m (2–6 feet) wide. It has an upright columnar to vase-shaped habit. Leaf size varies by cultivar, ranging from 0.6–5 cm (0.25–2 inches) wide and 0.9–1.5 m (3-5 feet) long. Leaves are medium green with or without silver, white, cream, or yellow variegation, depending on cultivar. Inflorescences resemble tassels and are borne above foliage, differing greatly by cultivar in time of emergence, color, location relative to foliage, and size. *Miscanthus sinensis*, with its numerous cultivars, is one of the most common ornamental grasses used in cultivation (Darke, 1999).

*Miscanthus sinensis* ‘Gracillimus’ is a fine-textured densely arched selection with 0.6 cm wide medium-green leaves, reaching up to 2.5 m (8 feet) in height. It bears pink inflorescences in the fall (Darke, 1999).

*Miscanthus sinensis* ‘Adagio’ is a fine-textured medium sized cultivar with 0.6 cm (0.25 inch) wide medium green leaves with a silver midrib. It reaches up to 1.5 m (5 feet) in height, and bears gold to pink inflorescences in late summer (Darke, 1999).

### ***Eragrostis spectabilis***

*Eragrostis spectabilis* (Pursh) Steud., purple lovegrass, is a member of Poaceae, Subfamily Chlorioideae, Tribe Eragrostidae (USDA, NRCS 2006). It is a native perennial clumping grass found in dry, sandy and disturbed sites throughout USDA zones 5–8 in the central and eastern U.S., Canada and Northern Mexico (Wunderlin and Hansen, 2003). *Eragrostis spectabilis* is a C4 plant that spreads by rhizomes, grows best in full sun, and is tolerant of drought and a wide range of soil types. In Florida, *E. spectabilis* is most often found in upland, non-wetland sites (US Fish & Wildlife Service, 1988). It is classified as an invasive plant in Nebraska and the Great Plains by the Nebraska Department of Agriculture (Stubbendieck, 1994). *Eragrostis spectabilis* has medium-green 1 cm (0.4 inch) wide foliage reaching 46–60 cm (18–24 inches) in height. The plant has a spiky, slightly coarse texture in landscapes. Purple-red spike inflorescences are borne above foliage in late summer to early fall, creating a ‘floating cloud’ effect above the leaves that is prized for its aesthetic value in landscapes (Darke, 1999).

## CHAPTER 3 DROUGHT TOLERANCE OF TWO ORNAMENTAL GRASSES

### **Introduction**

Drought and corresponding water restrictions are forcing landscapers and consumers to seek alternative irrigation practices and plants that require minimal irrigation for survival (Knox, 1990). Ornamental grasses are generally regarded as problem-free low maintenance plants (Dana, 2002), and are recommended to the public for their putative low-water requirements. A large body of research exists on the relationship between grasses and water use (Blicker et al., 2003; Bolger et al., 2005; Greco and Cavagnaro, 2002; Guenni et al., 2002; Mohsenzadeh et al., 2006), yet research quantifying water requirements of ornamental grasses for establishment and/or maintenance in the residential landscape is limited (Zollinger et al., 2006). Many water management districts have recommended native plants to their consumers (SFWMD, 2001; SFWMD, 2003) under the premise that Florida native plants use less water than non-native plants (Haehle, 2004; Hostetler et al., 2003; SFWMD, 2001). Limited research has been done to substantiate this assumption that native plants use less water than non-native plants. Kissel et al. (1987) examined water relations of four exotic and three native New Zealand species and found no overall difference existed between adaptation mechanisms of native and exotic species. Glenn et al. (1998) found no difference in water use efficiency between two native and two invasive riparian species from the Colorado River delta. However, Blicker et al. (2003) found that native *Pseudoroegneria spicata* (Scribn. And Smith) and *Pascopyrum smithii* (Rybd.) produced more biomass under drought conditions than invasive *Centaurea maculosa* (Lam). A study in Australia of seven native and three introduced perennial grass species subjected grasses to continuous drought and found mixed results among performance of native and exotic species (Bolger et al., 2005). Drought resistance may be less a function of a plant's status as native or

non-native, and more that of its individual physiology and natural range (Chapman and Auge, 1994). In addition, ecology of cultivated landscapes is not the same as natural environments. Plant selection should take into account individual site criteria and plants' cultural requirements in addition to their native or non-native status (Anella, 2000; Knox, 1990). The objective of this study was to evaluate non-native *Miscanthus sinensis* Anderss 'Adagio', a 1.5 m tall fine-textured C4 grass native to Asia, and the Florida native *Eragrostis spectabilis* (Pursh) Steud., a 0.5 m medium-textured grass, for drought response in a landscape setting.

### **Materials and Methods**

On 25 April, 2005, 6.3 cm liners of *E. spectabilis* and *M. sinensis* 'Adagio' were planted in native soil (Apopka fine sand series) in an open-sided clear polyethylene covered shelter approximately 4 m tall at the University of Florida Mid-Florida Research and Education Center in Apopka, Florida (lat. 28°41'N, long. 81°31'W). Thirty-two plants of each species were planted to original container depth in six rows on 0.6 m centers in 1.5 m wide strips in a randomized complete block design with four replicates. Planting rows were covered with 7.5-10 cm pine bark nuggets to a depth of 7.6 cm (Sunrise Landscape Supply, Inc., Orlando, Fla.). Areas between strips were covered with 0.9 m wide strips of polypropylene ground cloth (BWI Companies, Inc., Apopka, Fla.) to inhibit weed growth. Prior to transplant, soil under the shelter was saturated to a depth of 0.9 m.

Four levels of irrigation treatments were applied: 0L, 0.25L, 0.50L, and 0.75L. Irrigation was applied on alternate days for a 90 day period through 25 mm polyethylene pipe and 90° gray spray stakes (Roberts Irrigation Products, San Marcos, Calif.). Pressure compensators (Bowsmith Super-Drip N.D., Exeter, Calif.) were placed inline for each emitter to regulate water flow at 6.8 L/h. Two spray stakes were placed 0.46 m apart in the northwest and southeast directions to cover a 0.21 m<sup>2</sup> area around each plant. The Christiansen Coefficient of Uniformity

was a minimum of 0.77 prior to planting (Haman, Smaljstra, and Pitt, 1996). Irrigation of each experimental unit was controlled as a separate zone using an automated irrigation time clock (Model Sterling 12, Superior Controls Co., Inc., Valencia, Calif.). Irrigations began at 0500 HR and were completed by 0600 HR each day. Flow meters (Model C700TP, ABS, Ocala, Fla.) were installed for each zone to record irrigation volumes Monday through Friday.

### **Weather Data**

Weather data were obtained from a weather station site at the research site. Reference evapotranspiration ( $ET_0$ ) was calculated daily by a CR10X data logger (Campbell Scientific, Logan, UT, USA) using a program supplied in Campbell's Application Note 4D. This program calculates  $ET_0$  on an hourly basis using the ASCE Penman-Monteith equation with resistances (Allen et al. 1989). Input for  $ET_0$  calculations were measured with a pyranometer (Li-190, Li-Cor Inc., Lincoln, Neb. USA), anemometer (014, Met-One Instruments, Meford, Ore., USA), and temperature/humidity sensor (HMP45C-L, Campbell Scientific). Rainfall was recorded with a tipping bucket rain gauge (TE525, Texas Instruments, Dallas, TX, USA). Each midnight, the data logger calculated daily  $ET_0$ .

### **Growth Indices and Biomass.**

At planting, 6 plants of each species were partitioned into roots and shoots, washed to remove substrate, dried at 70°C for 168 h and weighed to obtain initial shoot and root dry mass values. Plant height, widest canopy width (width 1), and width perpendicular to the widest width (width 2) were recorded to calculate growth indices (growth index = height × width 1 × width 2) at transplant and every 14 d after planting. On 27 July 2005, the southernmost grass of each replication, the plant not used for water potential readings, was destructively harvested. Shoots were removed to the crown. To obtain root biomass gain, 1/4 segments of the soil volume outside of the root ball and extending beyond the longest root in each quadrant were removed

from the northeast and southwest sides of each plant. Substrate or soil was removed from roots, and shoots and roots were processed as described above. Dry masses of northeast and southeast segments were summed and multiplied by 2 to obtain total root biomass gain. Average initial root dry mass in the root ball and total root biomass gain were summed to obtain an estimated total root dry mass for calculation of shoot-to-root ratios. Shoot biomass gain was calculated as the difference between total shoot dry mass at final harvest and initial shoot dry mass. Total biomass gain was calculated as described for shoot biomass gain. Shoot-to-root ratios were calculated by dividing total shoot dry mass by total root dry mass.

### **Leaf Water Potential Measurements**

Beginning 1 month after transplant (MAT), on 23 May 2005, leaf water potential ( $\Psi_T$ ) was measured monthly. Measurements were made at predawn, mid-day, and dusk on the day prior to irrigation (stressed) and the day of irrigation (unstressed). Leaf water potential was determined with a pressure chamber (Model 3000; Soil Moisture Equipment Corp., Santa Barbara, Calif.) using compressed N<sub>2</sub>, with pressure increasing at a rate of 25 kPa·s. Measurements were made on individual grass blades ( $\approx$  10 cm long) taken from the northernmost plant of each replication. As described by Schulze et al. (1980) and Beeson (1992), cumulative daily water stress integrals ( $S_\Psi$ ) were calculated as the integrated area over a water potential curve and absolute value taken for each replication on each sampling date.

### **Data Analysis**

The experiment was conducted as a randomized complete block design with four blocks of single plant replicates. Regression equations were calculated for final growth data, consisting of shoot dry mass gain, root dry mass gain, biomass gain and shoot-to-root ratios as a function of irrigation rate for each species. Regression equations were also calculated for growth indices over time at each irrigation rate for each species. For final growth data, where at least one of the

regression lines were non-linear; data were analyzed as a  $2 \times 4$  factorial with two species and four irrigation rates. Similarly for growth indices, data was additionally analyzed as repeated measures by species due to non-linear responses over time. Analysis was by split plot, with irrigation rate as the main plot and month after transplanting as the subplot. Cumulative water stress integral values, predawn  $\Psi_T$ , midday  $\Psi_T$ , dusk  $\Psi_T$ , were analyzed as repeated measures using a split plot design with irrigation frequency as the main plot, species as a subplot, and stress day as a sub-subplot (Snedecor and Cochran, 1980). Each sampling date was analyzed separately. Where significant differences were indicated, mean separation was by Fisher's Protected least significance differences (F-Protected LSD, Snedecor and Cochran, 1980). All analysis was conducted using SAS (Version 9.1.3, SAS Institute, Cary, NC).

## **Growth Results and Discussion**

### **Mortality**

By 3 MAT, 75% and 25% of non-irrigated *M. sinensis* 'Adagio' and *E. spectabilis* plants, respectively, were dead. *E. spectabilis* plants receiving 0.25L per event had a 50% mortality rate.

### **Biomass**

Biomass gain of both *M. sinensis* 'Adagio' and *E. spectabilis* increased with increasing irrigation rates (Fig. 3-1A–C). Shoot, root, and total biomass gain of *M. sinensis* 'Adagio' and root gain of *E. spectabilis* increased quadratically while shoot and total biomass gain of *E. spectabilis* increased linearly (Fig. 3-1A–C). Shoot biomass gain was greatest at 0.75L treatments and lowest for non-irrigated plants. Shoot biomass gain of *E. spectabilis* was greater ( $P < 0.01$ ) than *M. sinensis* 'Adagio' for the 0.25L and 0.50L treatments, and similar ( $P > 0.05$ ) at 0L and 0.75L treatments (Fig. 3-1A). The 0.75L treatment increased shoot biomass gain of *E. spectabilis* by 131% and *M. sinensis* 'Adagio' by 404% relative to plants receiving 0.25L.

A treatment  $\times$  species interaction ( $P < 0.05$ ) occurred for root biomass gain. Root biomass gains decreased with decreasing irrigation levels. At 0L and 0.25L treatments, root biomass gain of *E. spectabilis* was higher than *M. sinensis* 'Adagio' (Fig. 3-1B). *M. sinensis* 'Adagio' irrigated at 0.75L per event had the greatest root biomass gains, with the lowest gains occurring in non-irrigated plants.

Irrigation rates of 0.75L resulted in greater ( $P < 0.0001$ ) total biomass gain than the 0L treatment. Total biomass gain of *E. spectabilis* was greater ( $P < 0.015$ ) than *M. sinensis* 'Adagio' (Fig. 3-1C). Average total biomass gain of *E. spectabilis* was greater than *M. sinensis* 'Adagio', by 74%, 176%, and 306% for the 0.75L, 0.50L, and 0.25L treatments, respectively (Fig. 3-1C).

Observed decreases in biomass with decreased irrigation quantities are well documented. Guenni et al. (2002) recorded a reduction in dry weight for *Brachiaria brizantha* (A. Rich.), an african neotropical grass, when it was subjected to moderate drought stress. Dry weights of drought-stressed *Gaillardia aristata* Pursh were reduced by 50% and 84%, and dry weights of *Leucanthemum  $\times$ superbum* (Bergmans ex J.Ingram) Soreng & E.A.Cope were reduced by 47% and 99%, respectively when exposed to 2- and 4-week intervals in irrigation (Zollinger et al., 2006). Greco and Cavagnaro (2002) subjected three varieties of native argentinean grass *Trichloris crinita* (Laq.) Parodi to drought conditions, all of which showed significantly reduced total dry weight as compared to controls receiving optimal irrigation. Fernandez et al. (2002) found a 60% reduction in biomass of drought stressed *Bouteloua eriopoda* Torr. and *Eragrostis lehmanniana* Nees.

### **Shoot-to-Root Ratio**

Shoot-to-root ratios of *E. spectabilis* were larger ( $P < 0.0001$ ) than *M. sinensis* 'Adagio' for all irrigation treatments (Fig. 3-2) with ratios of *M. sinensis* 'Adagio' represented quadratically, and *E. spectabilis* linearly. Ratios were similar ( $P > 0.05$ ) among treatments for *M. sinensis*

‘Adagio’. *Eragrostis spectabilis* plants irrigated with 0.75L had higher ( $P<0.05$ ) Shoot-to-root ratios than non-irrigated plants. All other treatments were similar ( $P>0.05$ ). This is consistent with Greco and Cavagnaro (2003), who found no significant difference in shoot-to-root ratios between levels of drought stressed *T. crinita*.

### **Growth Indices**

Mean growth indices for both species at 0.25L, 0.50L, and 0.75L irrigation treatments generally increased over time. Mean growth indices for the non-irrigated plants decreased over time (Fig. 3-3A–B). For *E. spectabilis*, growth indices for 0.25L, 0.50L, and 0.75L treatments, respectively increased by 28%, 49% and 71%. Growth indices of *M. sinensis* ‘Adagio’ receiving 0.25L, 0.50L, and 0.75L increased by 2-, 4-, and 8-fold, respectively. However, at 0L and 0.25L treatment rates, mean growth indices of both species decreased between 2 MAT and 3 MAT (Fig. 3-3A–B). Reduced shoot growth and decreased cell elongation are common effects of drought stress, having been observed in multiple experiments (Kalapos et al., 1996; Kramer and Boyer, 1996; Neumann et al., 1988; Sadras and Milroy, 1996; Sakurai and Kuraishi, 1988). In addition, significant leaf necrosis was observed with low irrigation levels. Zollinger et al., (2006) observed leaf death and senescence as a drought avoidance mechanism in herbaceous perennials.

An irrigation rate  $\times$  MAT interaction ( $P<0.05$ ) was found for both species. Growth responses corresponded to biomass gains with greater canopy size at higher application rates (Fig. 3-1A–C; Fig. 3-3A–B). For both species, canopy size was greatest ( $P<0.05$ ) at 0.75L and smallest within the 0L treatment. At 3 MAT, the 0.75L treatment increased mean growth index of *E. spectabilis* by 3.75 times relative to the 0L treatment and *M. sinensis* ‘Adagio’ by 7.5 times relative to the 0.25L treatment.

## Water Potentials

Treatment effects only occurred twice during the experiment. An irrigation effect was observed at 2 MAT for the midday  $\Psi_T$ , where 0L (-1.7 MPa) and 0.25L (-1.6 MPa) treatments were similar ( $P > 0.05$ ) yet more negative ( $P < 0.05$ ) than 0.50L (-1.2 MPa) and 0.75L (-1.2 MPa) treatments. At 3 MAT,  $S\psi$  was greater ( $P < 0.05$ ) for non-irrigated plants (24.0 MPa·h) compared to grasses receiving 0.25, 0.50, and 0.75L (19.3, 16.7, and 16.1 MPa·h, respectively). Cumulative water stress was comparable ( $P > 0.05$ ) between 0.75L and 0.50L treatments. For both sampling periods,  $\Psi_T$  became more negative as irrigation amount decreased, suggesting higher stress levels occurred as less water was applied to plants.

Species effects were seen at 2 MAT and 3 MAT for predawn, midday and dusk readings; each time,  $\Psi_T$  was more negative for *E. spectabilis* than for *M. sinensis* 'Adagio' except for 2 MAT predawn (Table 3-1). Cumulative water stress was greater ( $P < 0.05$ ) for *E. spectabilis* at 2 MAT than *M. sinensis* 'Adagio' (Table 3-1). Higher shoot-to-root ratios of *E. spectabilis* would account for increased water stress due to the inability of the root system to compensate for transpirational water losses (Gilman et al., 1998; Montague et al., 2000).

A stress day  $\times$  species interaction was observed in  $S\psi$  at 1 and 3 MAT (Fig. 3-4). At 2 MAT, there were no differences between stress days, but *E. spectabilis* had higher  $S\psi$  than *M. sinensis*. At 1 MAT,  $S\psi$  was highest for *E. spectabilis* on the day prior to irrigation (stress day) and lowest for *E. spectabilis* on the irrigation day (unstressed day). Cumulative water stress results were intermediate for *M. sinensis* 'Adagio' with comparable values between stressed and unstressed days. Results were similar for *M. sinensis* 'Adagio' at 3 MAT except regardless of stress day,  $S\psi$  was higher for *E. spectabilis* compared to *M. sinensis* 'Adagio' ( $P < 0.05$ ). For *E. spectabilis*,  $S\psi$  was higher on the unstressed day (24.9 MPa·h) than on the stressed day (19.7 MPa·h), ( $P < 0.01$ ) (Fig. 3-4). The results were likely due to weather effects. Around 1630 HR on

28 July 05, a 27 mm rainfall event (Table 3-2) occurred that reduced daily reference evapotranspiration (ET<sub>o</sub>), solar radiation (Table 3-2) and mid-afternoon vapor pressure deficits (VPD) (Fig. 3-5) compared to the unstressed day. Data suggest that stomatal conductance was reduced and caused *E. spectabilis* to transpire less. Consequently, plants displayed reduced cumulative water potential relative to a sunny, hot day when transpiration rates could be faster and S<sub>ψ</sub> higher. Similar results were reported by Fernandez et al. (2002), where improved leaf water status was seen with reduced stomatal conductance. Although reduction in stomatal conductance is a known effect of drought stress, it is also a known effect of decreased solar radiation and temperature reduction (Taiz and Zeiger, 2002). In this case, weather conditions appear to have caused a reduction in stomatal conduction of *E. spectabilis*, resulting in less negative water potentials.

### Conclusions

Across treatments, both grasses showed similar trends with increased biomass gain and growth index with increasing irrigation rates (Fig. 3-1A–C; Fig. 3-3A–B). The greatest portion of biomass gain for both species was shoot biomass, and little species effect was seen on root biomass gain. Shoot biomass gain of *E. spectabilis* was greater ( $P < 0.05$ ) than *M. sinensis* ‘Adagio’ across all treatments (Fig. 3-1A). Total biomass gain of *E. spectabilis* was greater ( $P < 0.05$ ) than *M. sinensis* ‘Adagio’ at all treatment levels above 0L (Fig. 3-1C). *Miscanthus sinensis* ‘Adagio’ has a larger mature size of 1.5 m (5 feet) than *E. spectabilis* 46-60 cm (18–24 inches), (Darke, 1999). Although it is overall a smaller plant, *E. spectabilis* showed greater biomass gain, mean growth indices, and larger shoot-to-root ratios across treatments. This is most likely a result of reduced growth rate of *M. sinensis* ‘Adagio’ due to drought stress, but could also be a result of a faster overall growth rate of *E. spectabilis*.

An additional possibility for increased gains of *E. spectabilis* is better drought tolerance. According to biomass and growth data, *M. sinensis* ‘Adagio’ did not perform as well under drought stress as *E. spectabilis*. However, consistently throughout the study *E. spectabilis* showed more negative water potentials than *M. sinensis* ‘Adagio’, which are ordinarily an indicator of higher water stress. Nonetheless, *E. spectabilis* had higher final dry mass, larger canopy size, larger shoot-to-root ratios, and less mortality than *M. sinensis* ‘Adagio’ (Fig. 3-1A–C; Fig. 3-3A–B). Larger shoot-to-root ratios were associated with faster and larger growth and more negative water potentials of *T. crinita* (Greco and Cavagnaro, 2003). These data are consistent with biomass data (Fig. 3-1), growth indices (Fig. 3-3), and water potentials (Table 3-1, Fig. 3-4) for *E. spectabilis*.

These data suggest that rather than avoiding drought through reduced growth and leaf senescence, *E. spectabilis* adjusted to drought physiologically through osmotic adjustment or larger stomatal aperture. Perdomo et al. (1996) found drought resistant kentucky bluegrass maintained a functional, green canopy and positive turgor under moderate or severe drought despite low ET and more negative water potentials through osmotic adjustment and larger stomatal aperture. Overall, *E. spectabilis* maintained higher levels of metabolic function under drought stress, suggesting that it is more drought-tolerant than *M. sinensis* ‘Adagio’. Although *E. spectabilis* is a native plant, its higher drought tolerance than *M. sinensis* ‘Adagio’ does not necessarily imply that native grasses outperform non-natives in drought situations. Water use and drought tolerance vary greatly from species to species, even varying by genotype within species. Careful evaluation of individual grass species and sites should always be performed when selecting plants for low-water use landscapes.

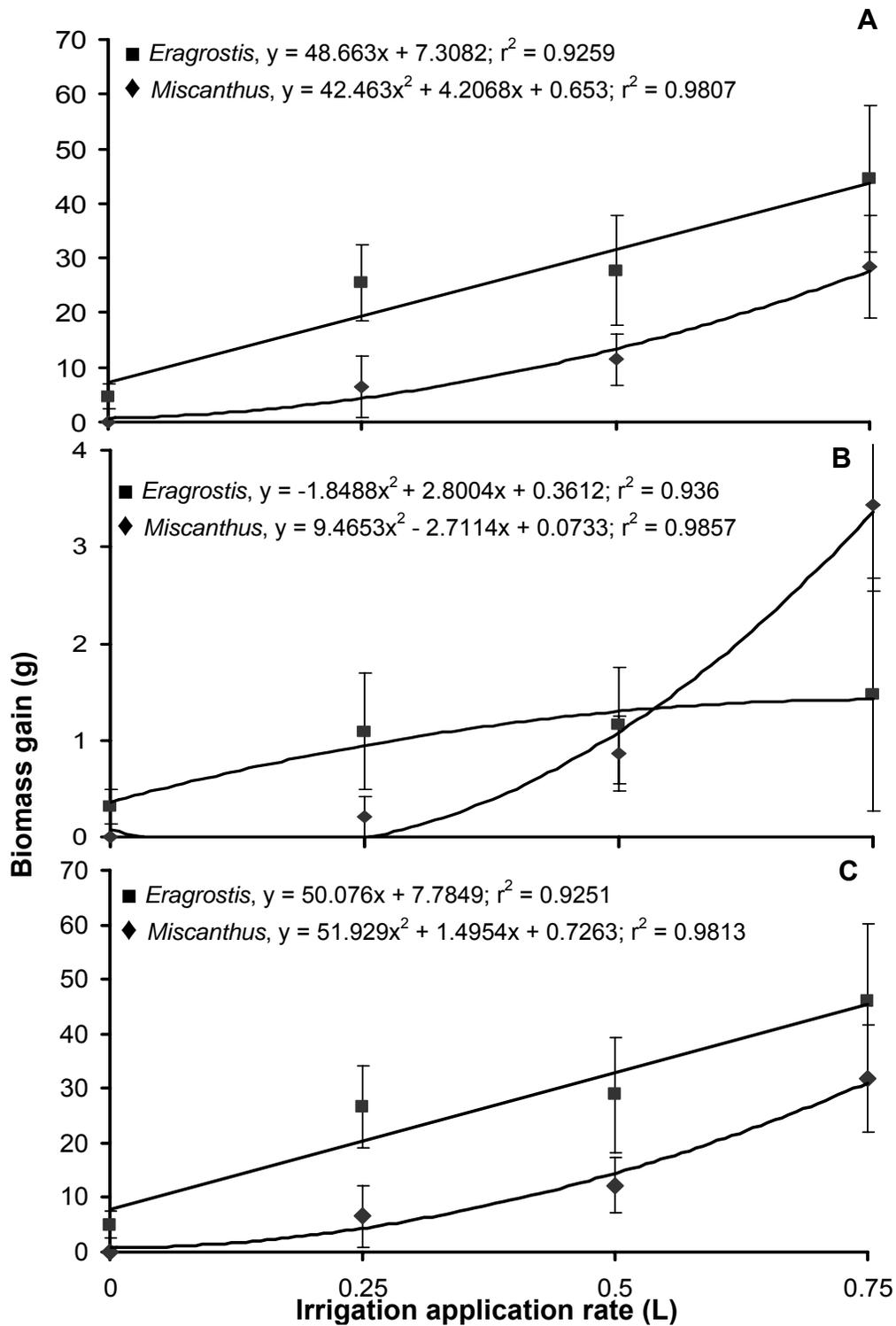


Figure 3-1. Biomass gains. A) Shoot biomass gain, B) Root biomass gain and C) Total plant biomass gain of (■) *E. spectabilis* and (◆) *M. sinensis* ‘Adagio’ grown for 90 days and irrigated every other day with 0, 0.25, 0.50 or 0.75L. Error bars indicate  $\pm$ SE.

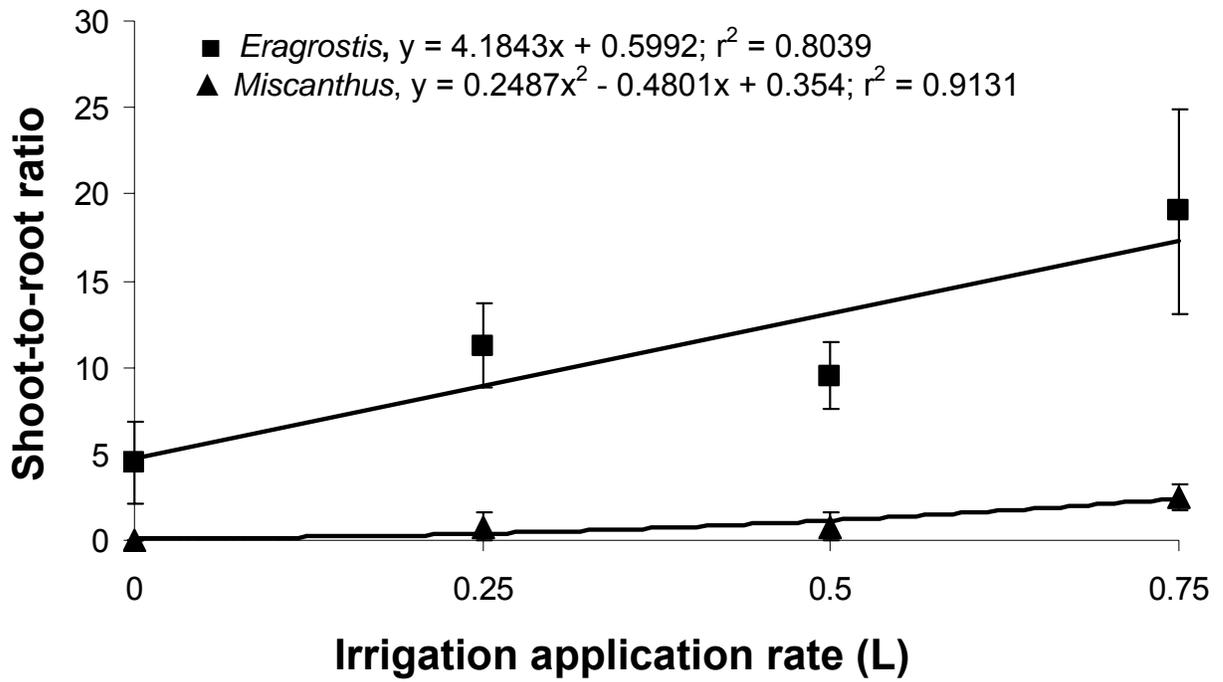


Figure 3-2. Shoot-to-root ratios. Ratios of *E. spectabilis* and *M. sinensis* ‘Adagio’ grown 90 d and irrigated every other day with 0, 0.25, 0.50 or 0.75L water. Error bars indicate  $\pm$ SE. Ratio calculated by dividing total shoot gain by total root gain.

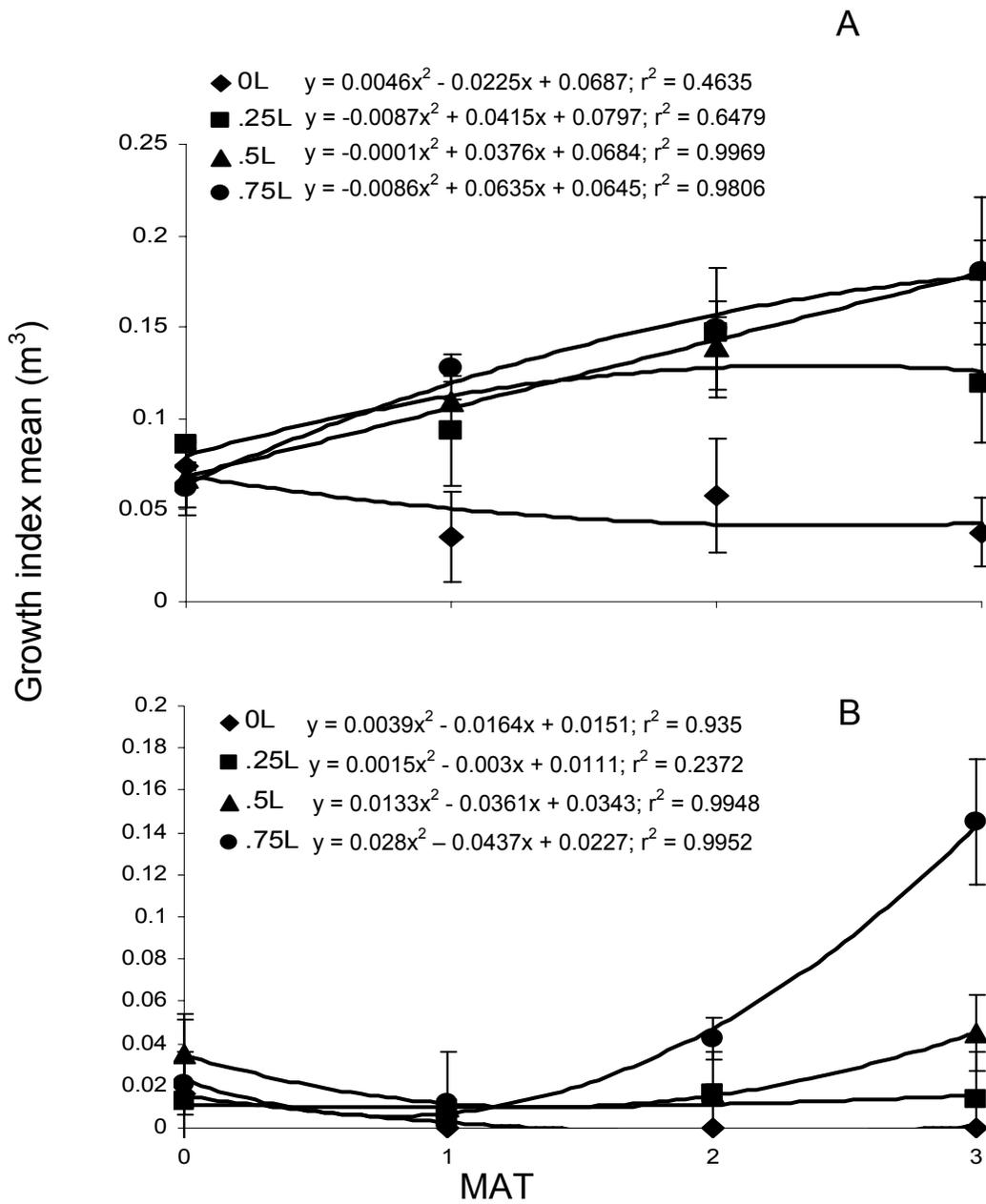


Figure 3-3. Growth indices. Mean growth indices for *E. spectabilis* A) and *M. sinensis* ‘Adagio’ B) irrigated at 0(◆), 0.25(▲), 0.5(■), and 0.75L(●) per event over a 3 month period during summer in central Florida.  $\pm$  SE indicated by standard error bars.

Table 3-1. Water potentials. Predawn, midday, dusk, and cumulative daily water stress integrals ( $S_{\Psi}$ ) calculated monthly for ornamental grass species irrigated with 0, 0.25, 0.50 or 0.75 L per irrigation event over a 3 month period during summer in central Florida.

MAT <sup>z</sup>	Species	Predawn $\Psi_T$ (MPa)	Midday $\Psi_T$ (MPa)	Dusk $\Psi_T$ (MPa)	Cumulative water stress, $S_{\Psi}$ (MPa·h)
2	<i>E. spectabilis</i>	-0.131 a <sup>yx</sup>	-1.67 a	-0.35 a	13.34 a
	<i>M. sinensis</i> 'Adagio'	-0.105 a	-1.02 b	-0.19 b	8.17 b
	p-values	$P<0.05$	$P<0.0151$	$P<0.0305$	$P<0.0149$
3	<i>E. spectabilis</i>	-0.216 a	-2.61 a	-1.13 a <sup>w</sup>	22.33 a <sup>v</sup>
	<i>M. sinensis</i> 'Adagio'	-0.129 b	-1.69 b	-0.28 b	12.92 b
	p-values	$P<0.0357$	$P<0.0005$	$P>0.05$	$P>0.05$

<sup>z</sup>Months after transplant.

<sup>y</sup>Means calculated from 4 single plant replicates.

<sup>x</sup>Mean separations within columns and species  $P<0.05$ .

<sup>w</sup>Values represent pooled dusk water potential species means; however, species effect cannot be clearly identified due to a significant species  $\times$  stress day interaction,  $P<0.05$ .

<sup>v</sup>Values represent pooled  $S_{\Psi}$  species means; however, species effect cannot be clearly identified due to a significant species  $\times$  stress day interaction,  $P<0.05$ .

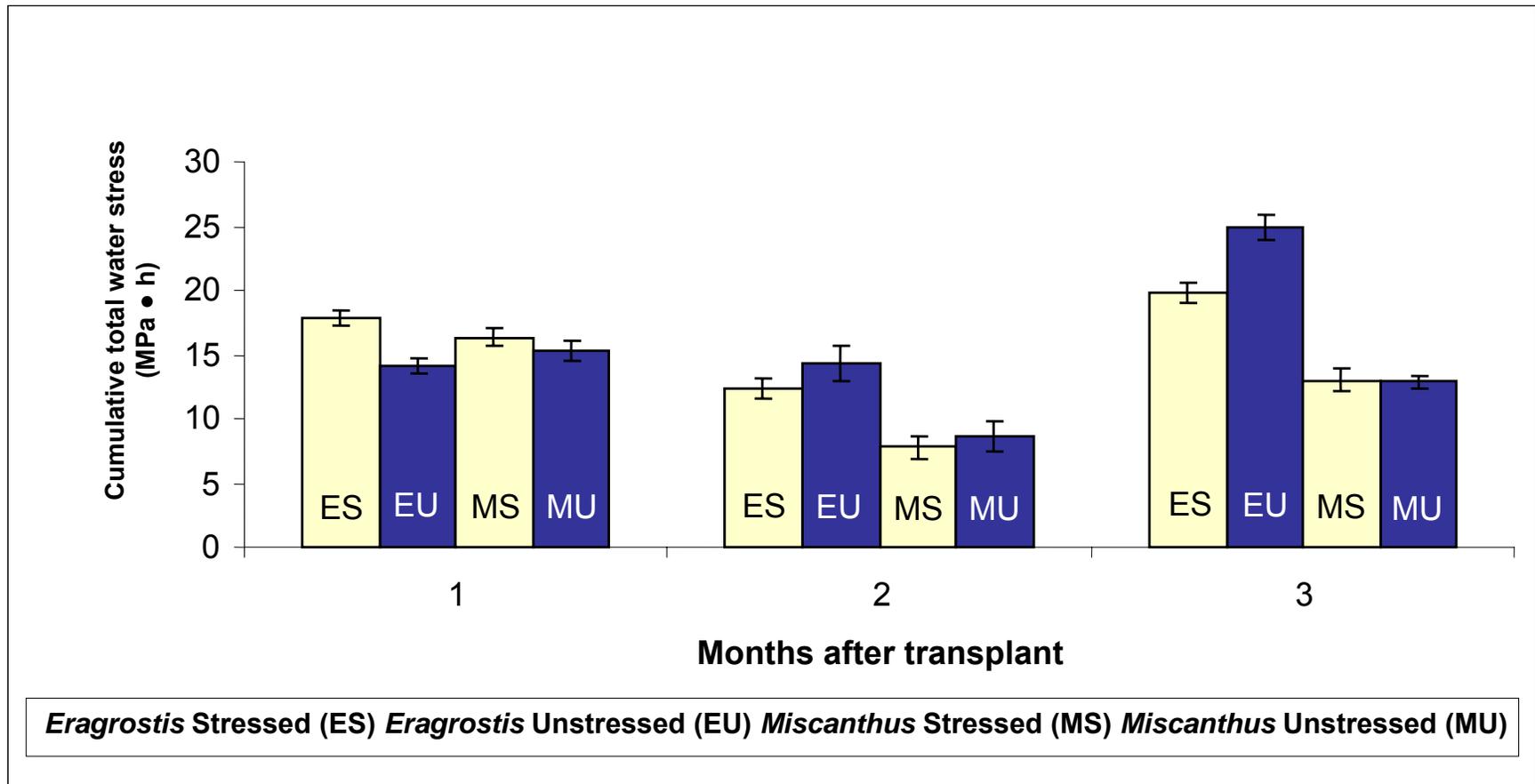


Figure 3-4. Water stress integrals. Cumulative daily water stress integrals ( $S\psi$ ) calculated monthly on the day prior to irrigation (stressed) and irrigation day (unstressed) for *E. spectabilis* and *M. sinensis* 'Adagio' irrigated with four irrigation rates (0, 0.25, 0.50, or 0.75 L) over a 3 month period in central Florida. Each bar represents means, vertical lines represent the SE.

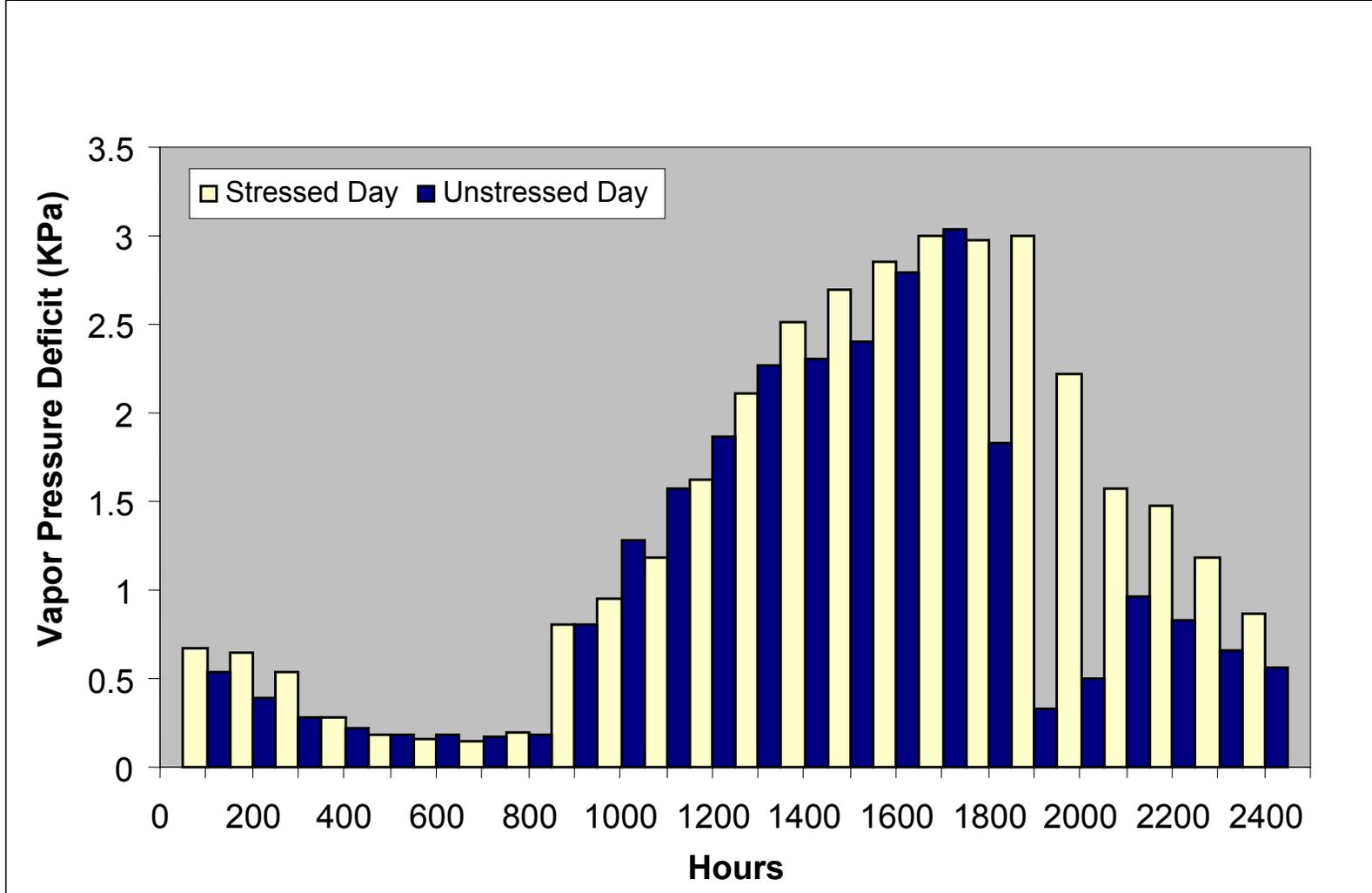


Figure 3-5. Hourly vapor pressure deficit (Vpd) recorded 27 (Unstressed Day) and 28 July (Stressed Day) 2005.

Table 3-2. Weather data. Daily maximum temperature, total incident radiation, precipitation, and reference evapotranspiration, ETo. Weather collected by an onsite weather station.

Date	MAT	Stressed/ Unstressed	Max Temp (°C)	Total Solar Radiation (Kw m <sup>-2</sup> )	Rainfall (mm)	ETo (cm)
5/23/2005	1	S	31.5	2748	0	0.253
5/24/2005	1	U	31.7	2174	0	0.2
6/23/2005	2	U	30.3	1428	0	0.135
6/24/2005	2	S	27.7	1324	10.4	0.118
7/27/2005	3	U	34.9	2681	0	0.251
7/28/2005	3	S	35.7	2149	26.9	0.203

## CHAPTER 4 SALT TOLERANCE OF TWO ORNAMENTAL GRASSES

### **Introduction**

As of 2003, 153 million people, 53% of the United States population, lived in the nation's 673 coastal counties (Crossett et al., 2005). As coastal development increases landscape plants that tolerate coastal conditions become critically important to the ornamental landscape industry.

Researchers have documented injury from airborne salts to plants growing near the coast (Edwards and Holmes, 1968; Karschon, 1964; Malloch, 1972). Exposure to water with high salt content reduces or inhibits plant growth (Belligno et al., 2002a, 2002b; Marcum, 2001; Qian et al., 2001). Much of the research conducted on salinity tolerance concerns saline soil or saline irrigation (Alshammary et al., 2003; Belligno et al., 2002a, 2002b; Gulzar et al., 2003; Hunter and Wu, 2005; Marcum et al., 1999, 2005), but little research has focused on exposure to salt spray under non-saline irrigation conditions. It is well documented that plants are often more sensitive to saline spray than to salt applied at the root zone (Benes et al., 1996; Bernstein and Francois, 1975; Grattan et al., 1981, 1994; Westcot and Ayers, 1984). In addition, most research has assessed survival rates of plants under saline conditions, but few studies considered aesthetic value of plants after foliage was exposed to water with high concentrations of salt (Marcum et al., 2005). For landscape plantings to be successful, they must not only survive but meet high aesthetic standards.

Many publications list suitable salt-tolerant ornamental landscape plants, but little quantified information exists for salt tolerance of individual ornamental grass species. The objective of this experiment was to determine the effect of four rates of salt spray on the appearance, flower number, growth and mortality of *Miscanthus sinensis* 'Gracillimus', a fine-

textured grass native to Asia reaching 2.5 m in height, and *Pennisetum alopecuroides* ‘Hamelin’, a medium-textured grass native to Asia reaching 0.50 m in height.

### **Materials and Methods**

On 1 July 2005, fifty-six 2.5-inch (6.3 cm) liners of *Miscanthus sinensis* ‘Gracillimus’ maiden grass and *Pennisetum alopecuroides* ‘Hamelin’ fountain grass (Emerald Coast Growers, Pensacola, Fla.) were potted into #1 (3.8L) containers and placed on a bench in a polyethylene greenhouse at the University of Florida Environmental Horticulture Greenhouse Complex in Gainesville, Fla. (29°38’N, 82°21’W). Potting media was 5 peat: 4 pine bark: 1 sand (by volume); (Florida Potting Soils, Inc., Orlando, Fla.). Irrigation was provided by 0.076 on-off tube/weight emitters (one per container; Chapin Watermatics, Inc., Watertown, N.Y.) connected to 1 inch (25.4 mm) polyethylene pipe. Plants received 0.13 gallons (0.5L) of water twice daily.

On 7 July 2005, 6 plants of each taxon were partitioned into roots and shoots, dried at 158°F (70°C) for 72 h and weighed. On 12 July 2005, carbon-filtered seawater with a salinity of 36,000 ppm was obtained from the Mote Marine Research Laboratory in Sarasota, Fla., separated into four 32-gallon (121L) refuse containers (Rubbermaid, Fairlawn, Ohio) and combined with deionized water to achieve the following treatment ratios: 1 seawater:0 deionized (100%), (36,000 mg·L<sup>-1</sup>), 1 seawater:1 deionized (50%), (18,000 mg·L<sup>-1</sup>), 1 seawater:3 deionized (25%), (9,000 mg·L<sup>-1</sup>), 0 seawater:1 deionized (0%), (0 v mg·L<sup>-1</sup>). Treatment applications began on 13 July 2005 and plants were treated 3 times weekly. At each application, foliage was sprayed to runoff with a 1L spray bottle. A bottomless 32-gallon (121L) container was placed over each plant at each application to prevent overspray to adjacent plants. Modified #3 (11.4L) plastic nursery containers were inverted and installed as pot covers to prevent salt spray from reaching the potting media.

Height, flower number, and visual rating data were collected biweekly. Height measurements only included green foliage. Visual ratings conducted by the same three observers at each data collection were based on foliage appearance, with 1 having no green foliage and 5 having all green foliage. In addition, root, shoot, total biomass gain, height gain (final – initial) were calculated. Mortality was also monitored throughout the data collection. After 90 days, plants were destructively harvested, partitioned into roots and shoots, dried at 158°F (70°C) for 72 h and weighed. The experiment was conducted in a completely randomized design. Height, flowering, and visual ratings were analyzed with regression analyses. To determine differences in biomass gains between species at specific treatment levels, mean separation was by paired t-tests. For height, flowering, and ratings, differences among all treatment combinations within species were determined with paired t-tests. All analysis was performed with SAS V8 (SAS Institute, Cary N.C.).

### **Results and Discussion**

In both ‘Gracillimus’ maiden grass and ‘Hamelin’ fountain grass, root, shoot, and whole plant biomass gain decreased as seawater concentration increased (Fig. 4-1A–C). Root biomass gain decreased linearly for both ‘Gracillimus’ maiden grass and ‘Hamelin’ fountain grass (Fig. 4-1A). These observations support previous findings that increased exposure to salt concentrations resulted in a decrease in root weight (Gulzar et al., 2003). In addition, Alshammary et al. (2004) found that root growth of kentucky bluegrass (*Poa pratensis*) reduced dramatically with increasing soil and irrigation salinity. Root biomass gain was similar between species ( $P>0.05$ ) at all treatment levels (Fig. 4-1A). Shoot growth and biomass are good indicators of salinity tolerance in both turfgrasses and forage grasses (Alshammary et al., 2004, Marcum and Murdoch, 1994; Marcum et al., 2005). Shoot biomass gain of ‘Gracillimus’ maiden grass and ‘Hamelin’ fountain grass decreased linearly and quadratically, respectively as seawater treatment

concentration increased (Fig. 1B). Shoot biomass gain was similar ( $P>0.05$ ) for grasses treated with 50% and 100% seawater; however, for grasses treated with 0% and 25% seawater, ‘Gracillimus’ maiden grass had a higher ( $P<0.001$ ) shoot biomass gain than ‘Hamelin’ fountain grass (Fig. 4-1B). ‘Gracillimus’ maiden grass is a larger, faster growing plant than ‘Hamelin’ fountain grass and would be expected to have greater biomass gain under optimal conditions. Reduced shoot biomass has been observed at high salinity levels in forage and turfgrasses (Alshammary et al., 2004; Hunter and Wu, 2005; Gulzar et al., 2003; Belligno et al., 2002b; Marcum et al., 2005). Shoot biomass was the major percentage of total biomass gained; therefore, the two displayed similar trends (Fig. 4-1B–C).

Height of ‘Gracillimus’ maiden grass treated with 0% and 25% seawater increased quadratically while 50% and 100% treatments decreased quadratically and linearly, respectively (Fig. 4-2A). Data indicate that height of ‘Gracillimus’ maiden grass is sensitive to increasing concentrations of salt spray and was reduced relative to plants not exposed to salt spray. ‘Hamelin’ fountain grass heights were similar ( $P>0.05$ ) among 0%, 25%, and 50% treatments but grasses treated with 100% seawater declined more rapidly ( $P<0.05$ ) resulting in shorter plants (Fig. 4-2B). Overall declines in height among treatments can be partially explained by the presence of chlorotic and necrotic leaves. As days after treatment initiation (DATI) and salt concentrations increased, chlorosis and necrosis increased, yet only green leaves were included in height measurements. This correlates with findings of Hunter and Wu (2005), who observed leaf chlorosis and necrosis as symptoms of salt stress in tufted hairgrass (*Deschampsia caespitosa*) and california melicgrass (*Melica californica*), as well as those of Marcum (1999), who found chlorotic leaf area to indicate salinity injury in forage and turfgrasses. Height data are consistent with shoot biomass gain (Fig. 4-1B).

Flower numbers for ‘Gracillimus’ maiden grass treated with 0%, 25% and 50% seawater increased ( $P<0.05$ ) with decreasing percent seawater applied though flowering did not occur until 70 DATI (Fig. 4-2C). ‘Gracillimus’ maiden grass plants treated with 100% seawater did not flower during the experiment (Fig. 4-2C). ‘Hamelin’ fountain grass flower numbers increased quadratically until 56 DATI. At 56 DATI, grasses treated with 100% seawater began to show decreased flower number. For both species, flower numbers were similar ( $P<0.05$ ) among grasses treated with 0%, 25% and 50% seawater but substantially declined within the 100% treatment (Fig. 4-2D). Hunter and Wu (2005) found no effect of salinity on flowering in native California grass species. In contrast, Munns and Rawson (1999) and Dhingra and Varghese (1997) observed an acceleration in the reproductive mode of plants under low levels of salt stress.

Throughout the experiment, visual ratings of ‘Gracillimus’ maiden grass and ‘Hamelin’ fountain grass were inversely correlated to salt spray level (Fig. 4-2E–F). Lower visual ratings were due primarily to the presence of chlorotic and necrotic leaves.

### **Conclusions**

Plants treated with 100% seawater displayed reduced height, flower number, and visual ratings (Fig. 4-2A–F). In addition, biomass of both species of plants decreased with increasing saltwater application rates (Fig. 4-1A–C). Of the two grass taxa, ‘Gracillimus’ maiden grass showed significant height and flower number reduction across treatments, where ‘Hamelin’ fountain grass only showed significantly reduced height and flower number at the 100% saltwater application rate. Under these experimental conditions, height and flowering of ‘Hamelin’ fountain grass were less sensitive to saltwater spray than ‘Gracillimus’ maiden grass. Neither plant is tolerant of 100% salt spray exposure, but at reduced levels of salt spray, ‘Hamelin’ fountain grass appears to be a more suitable selection for landscape use.

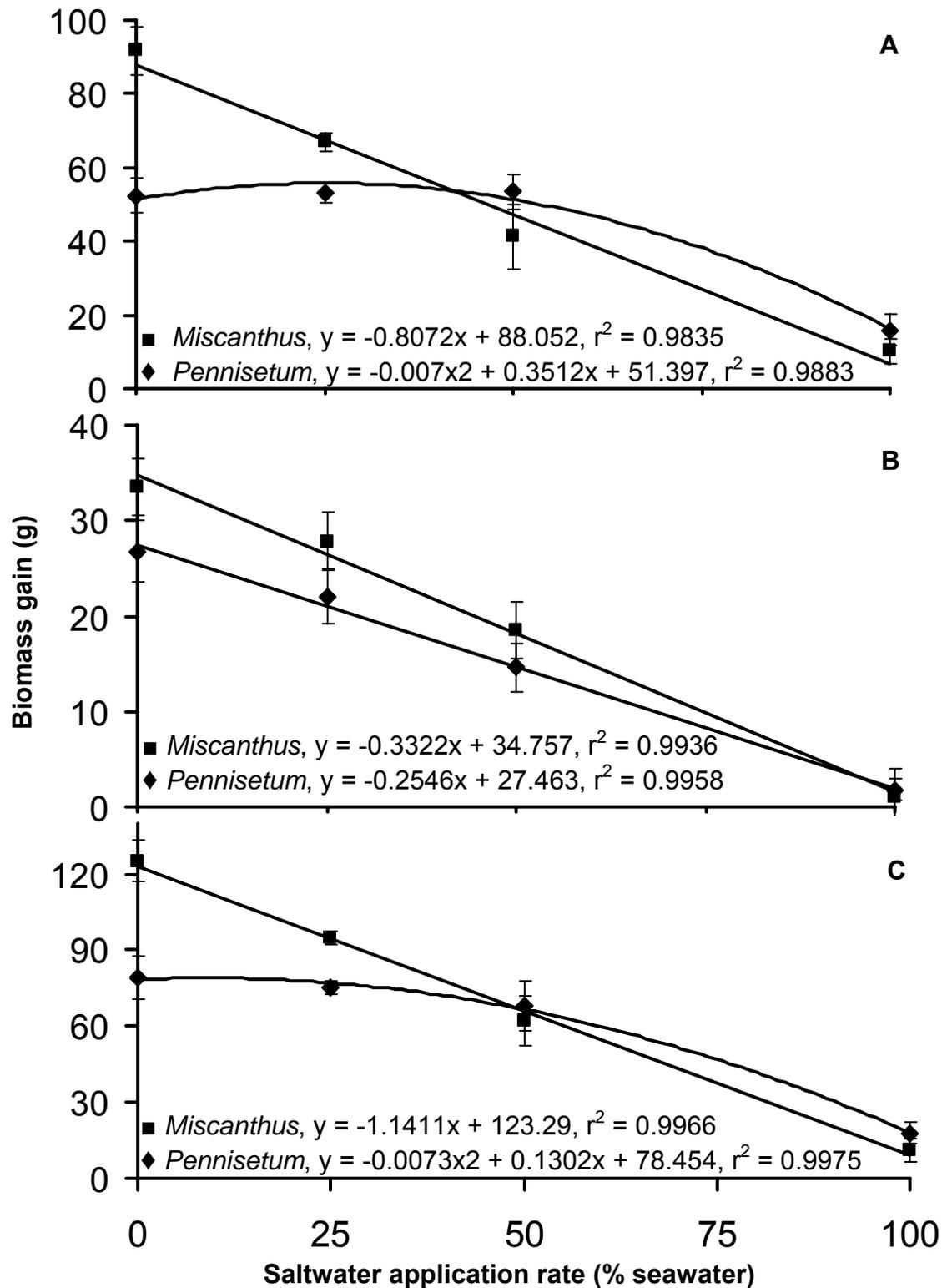


Figure 4-1. Biomass gain. A) Shoot biomass gain, B) root biomass gain and C) whole plant biomass gain of (■) *M. sinensis* ‘Gracillimus’ and (◆) *P. alopecuroides* ‘Hamelin’ grown for 90 d treated 3 × weekly with 0%, 25%, 50% or 100 % seawater spray. Error bars indicate ±SE.

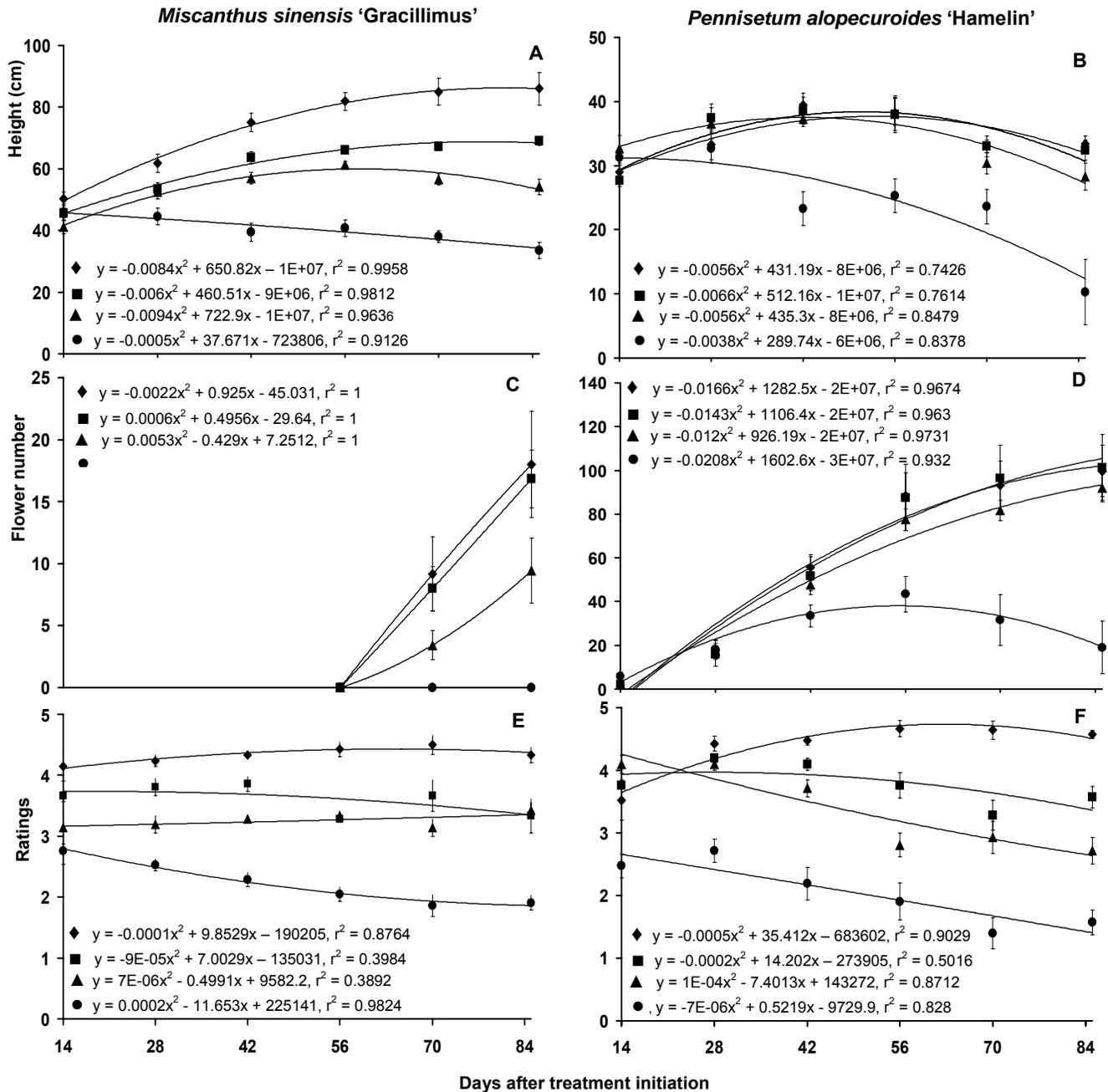


Figure 4-2. Aesthetic data. A) Height data for *M. sinensis* 'Gracillimus'. B) Height data for *P. alopecuroides* 'Hamelin'. C) Flower number for *M. sinensis* 'Gracillimus'. D) Flower number for *P. alopecuroides* 'Hamelin'. E) Aesthetic ratings of *M. sinensis* 'Gracillimus'. F) Aesthetic ratings of *P. alopecuroides* 'Hamelin'. All plants were grown for 90d and treated 3 × weekly with 0% (◆), 25% (■), 50% (▲), or 100% (●) seawater spray.

## CHAPTER 5 CONCLUSIONS

### **Drought Tolerance**

Drought tolerant plants are important to landscapers and consumers. Ornamental grasses are frequently recommended for low-maintenance landscapes and may be candidates for low-water use landscapes once they have been evaluated for drought tolerance. *M. sinensis* ‘Adagio’ and *E. spectabilis* were subjected to four irrigation treatments (0L, 0.25L, 0.50L and 0.75L) to determine drought tolerance. As irrigation level increased, root, shoot, whole plant biomass gain, growth index, shoot-to-root ratio, and cumulative water stress integrals increased for both taxa; however, *E. spectabilis* appears to be more tolerant of drought than *M. sinensis* ‘Adagio’. Although it is overall a smaller plant, *E. spectabilis* showed greater biomass gain, mean growth indices, and larger shoot to root ratios across treatments. This is most likely a result of reduced growth rate of *M. sinensis* ‘Adagio’ due to drought stress, but could also be a result of a faster overall growth rate and better drought tolerance of *E. spectabilis*.

Overall, *E. spectabilis* maintained higher levels of metabolic function under drought stress, suggesting that it is more drought-tolerant than *M. sinensis* ‘Adagio’. Although *E. spectabilis* is a native plant, its higher drought tolerance than *M. sinensis* ‘Adagio’ does not necessarily mean that native grasses outperform non-natives in drought situations.

### **Salt Tolerance**

Salt tolerant landscape plants are important to ornamental growers, landscapers and residents in coastal communities. Ornamental grasses are frequently recommended for low-maintenance landscape situations and may be candidates for coastal plantings once they are evaluated for their salt spray tolerance. Maiden grass (*Miscanthus sinensis* Anderss. ‘Gracillimus’) and fountain grass (*Pennisetum alopecuroides* (L.) Spreng. ‘Hamelin’) were

subjected to four treatments (100% seawater, 50% seawater, 25% seawater, or 100% deionized water) to determine salt spray tolerance. As seawater concentration increased, root, shoot, whole plant biomass gain, height, flower number, and visual quality decreased for both taxa; however, fountain grass appears to be slightly more tolerant of salt spray than maiden grass.

Water use and stress responses vary greatly from species to species, even varying by genotype within species. Provenance plays a significant role in plant adaptation to environmental stresses. Careful evaluation of individual taxa and site characteristics should always be performed when selecting plants for low-water use or coastal landscapes.

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## BIOGRAPHICAL SKETCH

Erin Elizabeth Alvarez was born on January 14, 1977, in Tampa, Florida. She grew up in Atlanta, Georgia, and Palm Harbor, Florida. She graduated from East Lake High School in Tarpon Springs, Florida in 1995. She earned her B.A. in English from the University of Florida in 1999. After graduation, she worked in advertising at the Independent Florida Alligator in Gainesville, Florida until 2001. She returned to school in the spring of 2001 and earned a B.S. in environmental horticulture from UF in 2004, and a M.S. in environmental horticulture in 2006. While in school, she worked as a landscape designer and student assistant for the Environmental Horticulture Department.

Erin plans to teach horticulture, and design residential landscapes. She also plans to work in conservation and education at a botanical garden or tropical ecology conservation center.