ESTABLISHMENT IRRIGATION STRATEGIES FOR FOUR WARM SEASON TURFGRASSES

By

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Limited research has been conducted investigating the timing and frequency of irrigation during establishment of warm-season turfgrasses, yet the water management districts in Florida regulate watering for lawns during this period. Field trials were conducted to test three irrigation strategies and two soil compaction levels on the establishment of four warm-season grasses at three different planting dates to potentially reduce establishment irrigation. Irrigation treatments included 1) a 30 day establishment period (15-15), where plots were watered every day for 15 days followed by every other day for 15 days; 2) a 60 day establishment period (30-30), where plots were watered every day for 30 days followed by every other day for 30 days; and 3) a no establishment (NON) irrigation treatment that was irrigated twice weekly from March until November and once weekly from December to February.

'Empire' zoysiagrass *(Zoysia japonica* Steud.), 'Floratam' St. Augustinegrass *(Stenotaphrum secundatum* (Walt.) Kuntze), 'Captiva' St. Augustinegrass, and 'Argentine' bahiagrass (*Paspalum notatum* Fluegge) were established to an acceptable quality under the 15-15 irrigation treatment when planted in June, leading to a 26% reduction in irrigation applied. When planted in Sept. or Jan., all grasses were

established to an acceptable level under the NON irrigation treatment leading to a 29 and 73% reduction, respectively, in irrigation applied. Soil compaction had no effect on visual quality the grasses but did have a negative effect on root growth resulting in an 11% reduction for bahiagrass, an 18% reduction for Captiva, and a 22% reduction for zoysiagrass in the total root length when planted on compacted soils.

CHAPTER 1
INTRODUCTION

After years of being viewed as an unlimited resource, water is now being viewed as a limited resource. As the population grows and drought periods increase, the concern over how water resources are used has also increased. Groundwater is the main source of freshwater in Florida. Groundwater withdrawals are expected to level off as this source reaches its sustainable limit (FDEP, 2010). In Florida, water management districts were formed to ensure that water is used in the best way possible to help protect and conserve resources for future uses. There are currently five water management districts that each serve a different watershed in the state, and because of this, water restrictions vary between districts. This study was located in the Southwest Florida Water Management District (SWFWMD) which serves Citrus, DeSoto, Hardee, Hernando, Hillsborough, Manatee, Pasco, Pinellas, Sarasota and Sumter counties, as well as portions of Charlotte, Highlands, Lake, Levy, Marion and Polk counties.

The mission of the SWFWMD is to manage water resources to ensure their continued availability while maximizing the benefits to the public (SWFWMD, 2014). One way the water management district accomplishes this is by implementing regulations and restrictions for the use of irrigation on residential lawns. As a non-food crop, turfgrass is constantly the focus of water conservation efforts. Irrigation accounts for nearly one third of all residential water use in the U.S. and this percentage increases in warmer climates (Mayer et al., 1999). In the SWFWMD, for an established lawn, watering is limited to twice per week from March until November and once per week from December to February. Watering is allowed any time before 10 am or after 4 pm, on specific days, which are based on home addresses. However, the district allows a

“30-30” establishment period for a newly installed lawn, when watering is allowed every day for the first 30 days and three days per week for the second 30 days (SWFWMD, 2013).

Establishment

For established turfgrass lawns, the typical recommendation is to water just often enough to maintain acceptable turfgrass quality (Richie et al., 2002). For newly planted lawns, more water is needed until the turfgrass is able to establish a healthy root system; this period of time is referred to as the establishment period. Depending on the species, environment, and season, the establishment period may last from weeks to months, during which time relatively high amounts of irrigation are needed to meet the transpirational demand of plants lacking an established root system (Wherley et al., 2011).

In most cases in Florida, new lawns are established vegetatively with sod. Sod is more expensive than other establishment methods but provides instantaneous turfgrass cover and minimal weed competition (Henderson et al., 2009). Sodded areas should be watered with approximately 12 mm of water per day and the area should remain moist for 10-14 days (Christians, 2004). During the first 7 days of that period it is important that the frequency of watering is increased to 2 to 3 times per day (Trenholm, 2009). After this time if the root system has established itself, watering should be reduced to longer, less frequent waterings on an as-needed basis (Trenholm et al., 2011). While it has been suggested that newly laid sod needs an increase in irrigation to help promote root growth, Peacock and Dudeck (1984) found no root growth response in St. Augustinegrass from different irrigation frequencies. Sinclair et al. (2011) also found that at reduced irrigation of only 13 mm wk^{-1} bahiagrass resulted in similar root mass as a well-watered treatment. Frequency of irrigation showed no effect on root growth within a turfgrass species and Sinclair et al. (2011) reported that there was no need to irrigate more than once a week when trying to promote root growth.

New construction is completed at various times of the year which means new sod is laid and establishing at different times of the year. The actual amount of water that a new lawn needs may differ based on when it was planted. For example, during a drought in the hot summer months, more frequent watering may be necessary during establishment to ensure an acceptable turfgrass quality (Trenholm et al., 2009). Ruemmele et al. (1993) laid bermudagrass (*Cynodon dactylon*), buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.], St. Augustinegrass, and zoysiagrass sod monthly from Oct. 1990 to Feb. 1992, and successfully established the turf each month. Sinclair et al. (2011) was able to successfully establish bahiagrass and zoysiagrass, in soil columns, regardless of time of year, but found that St. Augustinegrass established best in the early spring. Sprigging and plugging aren’t always successful at different times of the year. Compared to seeding or sprigging, a sodded lawn provides instant coverage, but can fail just as quickly if not managed properly (Trenholm, 2009).

Soil Compaction

Establishing a new turfgrass lawn is common in new home construction. The traffic and heavy equipment used during new construction typically results in increased soil compaction (Gregory et al., 2006), resulting in decreased porosity, increased bulk density, and decreased infiltration rates. A decrease in the infiltration rate of a soil profile can lead to increased runoff, flooding issues, and reduced groundwater recharge (Gregory et al., 2006). The incidence of potential turfgrass disease increases when standing water is present due to decreased infiltration rates of compacted soil (Harivandi, 2002).

Typically compaction is caused by the use of heavy equipment or grading of the lot, however, it can also be intentional in order to increase the structural strength of the soil for building purposes (Gregory et al., 2006). Compacted soil is necessary for building a house but can hinder the establishment of a new turfgrass lawn. Gregory et al. (2006) found that the compaction caused by heavy construction equipment resulted in a decrease of the infiltration rate from 73.4 cm per hour to 17.8 cm per hour. A decrease in water infiltration can make it difficult to properly irrigate the turfgrass (Harivandi, 2002).

A bigger issue related to soil compaction is the increase in soil bulk density, which can negatively impact root development and ultimately affect the plant's ability to extract soil moisture (Matthieu et al. 2011). Bulk density is a measurement of the total volume of solids and pore spaces in a soil sample (Hawver and Bassuk, 2007). When compaction is an issue, root accumulation will be greatest near the soil surface (Steinke et al., 2010). Previous research in turfgrass reported decreased root growth for Kentucky bluegrass (*Poa pratensis*) when bulk density is increased from 1.27 g cm^{-3} to 1.32 g cm^{-3}, perennial ryegraa (*Lolium perenne*) when bulk density is increased from 1.27 g cm^{-3} to 1.32 g cm^{-3}, tall fescue (*Festuca arundinacea*) when bulk density is increased from 1.32 g cm^{-3} to 1.34 g cm^{-3}, St. Augustinegrass when bulk density is increased from 1.6 g cm^{-3} to 1.8 g cm^{-3}, and zoysiagrass, bermudagrass, and centipedegrass (*Eremochloa ophiuroides* [Munro.] Hack.) when bulk density is increased 1.8 to 1.9 g cm^{-3} (Carrow, 1980; Matthieu, 2011). Previous research in agronomic crops reported decreased root growth for barley (*Hordeum vulgare* L.) when bulk density is increased from 1.64 g cm^{-3} to 1.78 g cm^{-3}, oats (*Avena sativa*) when bulk density is increased from 1.38 to 1.52 and wheat (*Triticum* spp.) when bulk density is increased from 1.33 to 1.52 (Oussible et al., 1992; Shuurman, 1965)

Soil texture affects the potential for compaction and increased bulk density. Soils with higher organic matter and clay soils tend to be more susceptible to compaction (Wolkowski and Lowery, 2008). Sandy soils can also become compacted, especially when the soil water content is at or above field capacity, due to a reduction in the soil bearing strength of wet sand (Wolkowski and Lowery, 2008).

Grass Species

Turfgrasses can be grouped according to their climatic adaptation. Warm-season grasses are better suited to tropical and subtropical areas, while cool-season grasses are better suited to temperate and sub artic areas (Huang, 2006). Florida's climate allows for successful growth and management of warm season turfgrasses.

St. Augustinegrass is one of the most predominately used grass species for residential lawns in the southeastern United States (McGroary, 2011). St. Augustinegrass is estimated to be planted on 70% of the lawns in Florida (Haydu et al., 2005). St. Augustinegrasses typically have a dense, coarse textured canopy that can produce an acceptable stand of turf for use in lawns with moderate maintenance (Hanna et al., 2013). St. Augustinegrasses are not strong seed producers and are typically propagated by sod, sprigs, or plugs. St. Augustinegrass can spread fairly quickly due to its stolon growth. In a study by Steinke et al. (2010), 'Floratam' when subjected to drought, recovered more quickly than other St. Augustinegrass cultivars. 'Floratam' is not very shade or cold tolerant and grows best during the spring and summer seasons (Trenholm and Unruh, 2005). ‘Captiva’ is a dwarf cultivar of St. Augustinegrass (Trenholm and Kenworthy, 2009). It has darker green, shorter leaf blades and a reduced vertical leaf extension (Cai et al., 2011). This cultivar is slower growing than ‘Floratam’. This reduced growth rate does not affect the ability of ‘Captiva’ to establish as sod, but is actually considered an improvement as it can result in less frequent mowing (Trenholm and Kenworthy, 2009).

While St. Augustinegrass is the most widely used grass for home lawns in Florida, it has been suggested that bahiagrass should be used instead because its lower irrigation requirement and higher drought tolerance (McGroary et al., 2011). Bahiagrass was introduced from Brazil in 1914 (Trenholm and Unruh, 2005). In the past 20 years, the use of bahiagrass for lawns has increased because it is considered a low input turfgrass. Before this time it was always viewed as an option for roadsides and pastureland (Christians, 2004). Bahiagrass can be successfully propagated by seed or sod (Trenholm and Unruh, 2005). Seed is cheaper, but sodding bahiagrass helps to reduce the amount of weed pressure during establishment, as seed establishment takes much longer than sod establishment (Trenholm and Unruh, 2005). Mature bahiagrass has a medium texture with thick rhizomes, yet it doesn’t grow to be very dense (Christians, 2004). It is adapted to poor soils, low fertility, and low rainfall, but requires frequent mowing due to its rapid seedhead production (Trenholm and Unruh, 2005). Bahiagrass is able to survive solely off summer rainfall due to its extensive root system (Hanna et al., 2013). It can also survive the dry winter months because if its ability to go into dormancy (Hanna et al., 2013).

Another turfgrass that is gaining popularity for use in lawns in Florida is zoysiagrass. Zoysiagrass is native to Southeast Asia and has adapted well to the Southeastern United States. Zoysiagrass produces both rhizomes and stolons. Its texture varies between cultivars, but overall it is able to produce a thick dense stand with its stiff vertical leaf blades (Christians, 2004). A lower fertility requirement and slower growth habit make zoysiagrass it ideal for use in lawns. Zoysiagrass can be very cold and shade tolerant (Hanna et al., 2013).

Zoysia japonica is the only zoysiagrass species that has commercially available seed. The seeded varieties do not establish as well as other vegetatively propagated varieties do (Unruh et al., 2013). Because of this, zoysiagrass is usually sodded, sprigged, or plugged when installed as a lawn. Like other grasses, sodding provides instant coverage reducing the pressure from encroaching weeds during establishment. During a drought period, zoysiagrass will turn brown, enter dormancy, and stay in dormancy for 40 to 45 d (Qian and Fry, 1997). Its green color starts to come back once irrigation is applied or rainfall begins (Unruh et al., 2013).

Bermudagrass is a warm season turfgrass that produces a vigorous, medium green, dense turf that is well adapted to most soils and climates found in Florida (Trenholm et al, 2011). Bermudagrass is commonly grown on athletic fields, golf courses, and some residential areas. Bermudagrass can be established by sod, plugs, or for some varieties, by seed. Bermudagrass varieties grown for lawn use in Florida include ‘Common’, ‘Celebration’, ‘Tifway’, and ‘Discovery’. Bermudagrass is used in Florida because it has good drought tolerance and only needs to be watered when it begins to wilt. Bermudagrass will go into dormancy during an extreme drought and will resume growth once adequate water is received. Its popularity in the sports turf industry comes from its great wear tolerance. Bermudagrass has a fast growth rate and is able to establish and recover from injury due to its ability to spread rapidly by stolons and rhizomes (Higgins, 1998). Healthy bermudagrass produces a dense stand of turf that allows the grass to out compete weeds.

While bermudagrass can provide homeowners with a high quality lawn, it also comes with a high level of maintenance and can require mowing multiple times a week depending on its height of cut. It has good tolerance to wear and compaction but also requires high nitrogen (N) for good quality turf (Christians and Engelke, 1994). Bermudagrass has poor shade tolerance. Certain pests, like nematodes and mole crickets, increase the required maintenance of bermudagrass. It is also prone to thatch build up because of its growth habit. Another major downside of using bermudagrass in home lawns is that in some cases its vigorous rhizomes can turn it into a troublesome weed in adjacent flowerbeds (Wiecko, 2006).

Centipedegrass is adapted to Florida and the Gulf Coast region, however it can be found in North Carolina and Georgia (Christians, 2004). It does not do well in the sandier soils of Southern Florida and is more commonly found in Northern Florida and the panhandle (Trenholm and Unruh, 2005) where the soils have a higher clay content (Ferrell et al., 2012). Centipedegrass is medium textured with a more yellow green color. It does well with low fertility and will begin to decline if over fertilized (Han, 2008). It is a slow growing turfgrass that requires minimum maintenance. It can be established by seed, plugs, or sod and spreads by stolons. The stolon growth can lead to thatch accumulation, which can result in reduced cold tolerance (Han, 2008). One major issue with centipedegrass is centipedegrass decline. This decline can be attributed to over fertilizing, excessive thatch buildup, or stress from fungi, nematodes, or drought (Han, 2008). Minimizing fertilizer inputs, proper mowing, and thatch control can help reduce the onset of decline. Mowing should be done every 7 to 14 days to help promote deeper root growth (Trenholm et al., 2000).

Seashore paspalum (*Paspalum vaginatum*) is perennial grass that is adapted to moist, salt affect areas which allows for successful growth in coastal regions (Raymer et al., 2007). It has a dark green color and varieties that are coarser textured (used for roadsides), or finer textured (used on golf courses and in landscapes) (Brosnan and Deputy, 2008). Paspalum grows with both stolons and rhizomes and is typically established through sodding, sprigging, or stolonizing (Brosnan and Deputy, 2008). It is increasingly being used more inland, which has led to more disease issues such as dollarspot (*Sclerotinia homoeocarpa*), large patch (*Rhizoctonia solani*), fusarium blight (*Fusarium roseum*), and take all patch (*Gaeumannomyces graminis* var. *graminis*) (Raymer et al., 2007; Brosnan and Deputy, 2008). Potential pests include mole crickets, sod webworms, spittlebugs, white grubs, and fall armyworms (Brosnan and Deputy, 2008). Compared to other warm-season turfgrasses, paspalum is able to produce high quality stands in reduced light, waterlogged soils, and less nitrogen fertilizer inputs (Brosnan and Deputy, 2008).

Shade tolerance, cold tolerance, and management needs are all important when considering which turfgrass to plant. However, due to growing water restrictions, water requirements of the different turfgrass species is the most important factor. While research on the water use of turfgrass during establishment is limited, there is research on water use for mature turfgrasses. Turfgrass water use is the combination of water that was taken up by the roots and transpired and water that was evaporated from the soil (Leinauer et al., 2010). This is commonly referred to as turfgrasses evapotranspiration (ET). Turfgrass ET varies between species, location, and management. Qian and Engelke (1999) found that turfgrasses that were subjected to reduced water inputs or reduced soil moisture actually used less water than turfgrasses that were in well-watered conditions. During drought stress, zoysiagrass that was watered daily declined in quality faster than zoysiagrass that was only watered at first sign of leaf rolling (Qian and Fry, 1996).

Warm-season turfgrasses typically use between 3 to 9 mm day^{-1} of water (Romero and Dukes, 2013). Most warm-season grasses can be irrigated less than full ET replacement and still maintain acceptable quality. Meyer and Gibeault (1986) found that warm season turfgrasses could maintain acceptable quality when irrigated at 43-63% of ET. Garrot and Mancino (1994) found that bermudagrass could be irrigated between 57 and 64% ET and still maintain acceptable quality. Carrow (1995) saw similar results with bermudagrass maintaining quality at 66% ET. He also found that zoysiagrass and St. Augustinegrass could maintain quality levels at 80 and 76% ET, respectively. Fu et al. (2004) found that bermudagrass and zoysiagrass were able to maintain acceptable quality at 60 and 80% ET, respectively. While these rates are primarily for mature turfgrass stands, Sinclair et al. (2011) found that successful sod establishment is possible under a modest, infrequent deficit irrigation regime when established on soil columns in a greenhouse environment. A deficit irrigation regime is a watering schedule that irrigates below the maximum water demand of the turfgrass stand (Wherley, 2011).

There is a lack in research on the effect of irrigation needed during the establishment of a warm season turfgrass lawn. The objectives of this study were to 1) determine the effect of irrigation frequency needed to establish turfgrass species during specific seasons while maintaining acceptable quality and 2) to determine the effect of irrigation treatments and soil compaction on the establishment of the turfgrass. It is thought that using a reduced establishment irrigation regime can lead to water savings, while still establishing acceptable quality turfgrass.

CHAPTER 2
MATERIALS AND METHODS

Installation of field plots began with the clearing of land at the Gulf Coast Research and Education Center facilities in Balm, FL. A series of tillage and chemical treatments were applied to the site to remove all existing vegetation. Topsoil at the research site was excavated to a depth of 8 in. using a soil pan. Clean soil fill was excavated from the Shelly Lakes facility in Balm, FL and transported to the research site. The soil used was from an area that was classified as Archibold fine sand; however, the soil used was taken from 30.5 m below ground. The soil fill material is typical of what is used locally as topsoil fill at residential communities (i.e., Fishhawk Ranch). The fill material was then spread over the entire plot area to a depth of 8 in. The soil was rolled flat. The entire site was fumigated using an 80/20 mixture of methyl bromide/chlorpicrin and was covered with clear plastic for a period of 2 weeks. Once site re-entry was allowed, the plastic was removed from the research site.

Once field site was prepped, irrigation pipes were assembled in lateral “loops” for individual plots. Irrigation supply pipes were assembled in trenches and connected to the plot pipe loops. After all piping was installed, trenches were backfilled and the study area was re-leveled. A 10.2 cm diameter water supply line was connected to the manifold to provide ample water supply to run 64 spray heads per irrigation zone. The supply and distribution manifold included pressure regulation at 40 psi, solenoid valves, and flowmeters for each valve. Sprinkler heads were installed at the corners of each sub plot. Irrigation was applied with Hunter (Hunter Industries, San Marcos, CA) 15.2 cm Pro-Spray pop-up heads with Hunter MP Rotator 1000 nozzles (2.4 m radius, ¼ circle arc). The heads had an average application rate of 0.21 gal min^{-1}. Once irrigation system was finished plots were laid out and treatments were assigned.

Whole plots were 13.4 m^2 (7.3 m x 1.8m) and consisted of the following grass types: 'Argentine' bahiagrass, 'Captiva' St. Augustinegrass, 'Floratam' St. Augustinegrass, and 'Empire' zoysiagrass which were assigned in a random complete block design (Figure 2-1). Sub-plots were 4.5 m^2 (2.4 m x 1.8m) and consisted of the following irrigation treatments: 15-15 establishment irrigation program, 30-30 establishment irrigation program and a maintenance only irrigation program (Table 2-1). Water meters associated with each treatment for each season were read daily to track the total volume of water applied to the plots with each irrigation event. The volume of water applied in liters was converted to depth applied (mm) by dividing volume of water applied by irrigated area and converting to appropriate units. All treatments received approximately 10-12 mm of cumulative water on days when irrigated.

Tables 2-2 and 2-3 represent the irrigation schedules for the two establishment irrigation treatments. Taking into account Trenholm (2009) suggesting multiple irrigation events during the first week of establishment, both establishment irrigation treatment schedules begin with 3 time d^{-1} for the first 5-10 d followed by 2 times d^{-1} for the next 6-20. A Toro RainSensor Switch (The Toro Company, Bloomington, MN) expanding disk rain sensor was installed and set to activate once it received 6 mm of rain or more to ensure that plots did not receive unnecessary irrigation applications. On the day that sod was laid, irrigation was applied in three, 30 min cycles to insure that the soil was moist to a depth of 15 to 30 cm. On the day after the sod was laid, all irrigation treatment programs commenced. The NON irrigation treatment was irrigated twice weekly from March until November and once weekly from December to February; no additional irrigation was applied during the 60 day establishment period.

Sub-sub-plots were 2.2 m^2 (2.4 m x 0.9 m) and were either compacted or un-compacted. Plots were tilled first, then a plate compactor (Wacker Neuson, Munich, Germany) was used on half of the plots to compact the soil (Loper et al., 2013) to an average bulk density of 1.7 g cm^{-3}. Tilled only or un-compacted plots had an average bulk density of 1.6 g cm^{-3}. Bulk density was calculated for this study by collecting one sample from each plot for each planting date. All samples were dried and weighed. The dry weight was divided by the volume of the original sample to determine bulk density of each plot. Each planting consisted of 96 sub-sub-plots and all data were collected on these individual sub-sub plots, unless otherwise noted.

The study period consisted of six different planting dates in order to take into account potential seasonal differences. The planting dates were as follows: 16 June 2011, 7 Sept 2011, 10 Jan 2011, 19 June 2012, 4 Sept 2012, and 9 Jan 2013. Each planting was monitored for 300 days, after which, turfgrass was removed and the plots were prepped for the next planting date. For clarity, June planting dates are referred to as “summer”, September planting dates are referred to as “fall”, and the January planting dates are referred to as “winter”. For each planting date, treatments were arranged in a spilt-split plot design with four replications.

Plots were maintained and fertilized according to UF-IFAS recommendations for maintenance of residential lawns in South Florida (Trenholm and Unruh, 2005). A 14-7-14 fertilizer, that was 50% slow release nitrogen (N), was used at a rate of 0.45 kg ha^{-1}. Three separate fertilizer applications took place each year in Apr., June, and Aug. Sod from new plantings were not fertilized until after the 60 d establishment period. During the late summer and early fall of 2011 there was a take-all root rot (*Gaeumannomyces graminis* var. *graminis*) disease outbreak. All plots were treated with azoxystrobin (Heritage [Syngenta, Greensboro, NC]) and fertilized with a micronutrient mix (S.T.E.M., The Scotts's Company, Marysville, OH) so that 0.45 kg ha^{-1} on manganese was applied. In order to keep the disease from damaging future plantings, a preventative treatment with a mix of trifloxystrobin and triadimefon (Armada [Bayer Environmental Science, Research Triangle Park, NC]) was sprayed after each planting.

The plots were mowed once a week from April through October and then as needed from November through March using 4 Toro Personal Pace mulching/bagging mowers (The Toro Company, Bloomington, MN). One mower was assigned for each grass species and all clippings were collected to help prevent any contamination. Each grass type was mowed at the following heights: 6.4 cm for 'Empire' zoysiagrass, 10.2 cm for 'Floratam' St. Augustinegrass, 7.6 cm for 'Captiva' St. Augustinegrass, and 7.6 cm for 'Argentine' bahiagrass. Biomass was collected monthly.

Rainfall and temperature were monitored throughout the duration of the study utilizing the on-site weather station that is managed by the Florida Automated Weather Network (FAWN) (http://fawn.ifas.ufl.edu/). The weather network also provided daily estimated reference evapotranspiration (ETo). Thirty year historical rainfall averages were calculated using monthly rainfall data from 1975 through 2005 from the National Oceanic and Atmospheric Administration weather station located in Parrish, FL (approximately 27 km away) (NOAA, 2005).

Visual quality ratings were collected to monitor turfgrass establishment. These ratings were conducted in accordance with the guidelines established by the National Turfgrass Evaluation Program (NTEP) (Morris and Shearman, 2006). Turf quality was rated on a scale of 1 to 9, with 1 indicating the poorest quality (dead turfgrass), 5 indicating minimally acceptable quality, and 9 indicating the optimum quality (uniform, healthy turfgrass).

Digital images of each plot were collected using a Sony DSC-H5 camera (New York, NY) set on the automatic feature. In order to reduce shadowing and maintain consistency of photos the camera was mounted to a portable light box that provided an enclosed area with artificial light. The light box was 30.5 cm x 30.5 cm x 30.5 cm in size and had 4 ten-watt compact florescent light bulbs mounted inside. Photos were uploaded to the computer and resized to an area of 1 megapixel using ACDSee Pro (v. 3, ACD Systems International Inc., Victoria, British Columbia) for use with the "Turf Anaylsis Macro" (Karcher and Richarson, 2005) written for use with SigmaScan Pro Software (v. 5, SPSS, Inc., Chicago, IL 60611) to calculate the percent green cover for each image. The macro accomplishes this by counting the number of green pixels in the set target range (hue 57-107, sat 0-100) and divides it by the total number of pixels in the photo. This parameter provides a more quantitative measure of plant quality.

Collection of visual ratings and digital images began when treatments were initiated (one day after planting) and collection continued 3d wk^{-1} for the first 15d. From 16d-90d all evaluations were collected on a weekly basis to monitor any change in turf quality during and immediately after the establishment period. From 90d-300d evaluations were collected every two weeks.

The effects of compaction were monitored by collecting root length data at the end of the monitoring period (day 300) for all seasons. Root samples were collected using a 5 cm diameter soil corer to a depth of 30 cm. The above ground biomass was removed and the sample was sectioned based on 3 depths: 0-7.5 cm, 7.5-15 cm, and 15-30 cm. Each individual root sample was washed free of soil and debris and scanned to create a digital image using an Epson Perfection V700 Photo Scanner (Epson America, Inc., Long Beach, CA, 90806). The images were analyzed using WinRHIZO Pro v2007d software (Regent Instruments, Inc., Canada) to calculate total root length for each sampling depth.

All data were analyzed using a generalized linear mixed model (Proc Glimmix) with appropriate error terms to test the interactions between year, season, time, irrigation, and compaction (SAS, 2009). A sample table of fixed effects can be found in Table A-1. Residuals were analyzed for normality visually with a histogram and q-q plot. Based on the study design and the required approach for analysis, LS means were compared at a p-value of 0.05 using the Tukey multiple comparison procedure. Results are presented for each individual grass species.

Table 2-1. Irrigation treatment descriptions

Treatment	Description
15-15	Irrigation every day for 15 days, every other day for 15 days
30-30	Irrigation every day for 30 days, every other day for 30 days
NON	No establishment irrigation (once or twice per week irrigation, depending on time of year)

Table 2-2. 15-15 establishment irrigation treatment schedule.

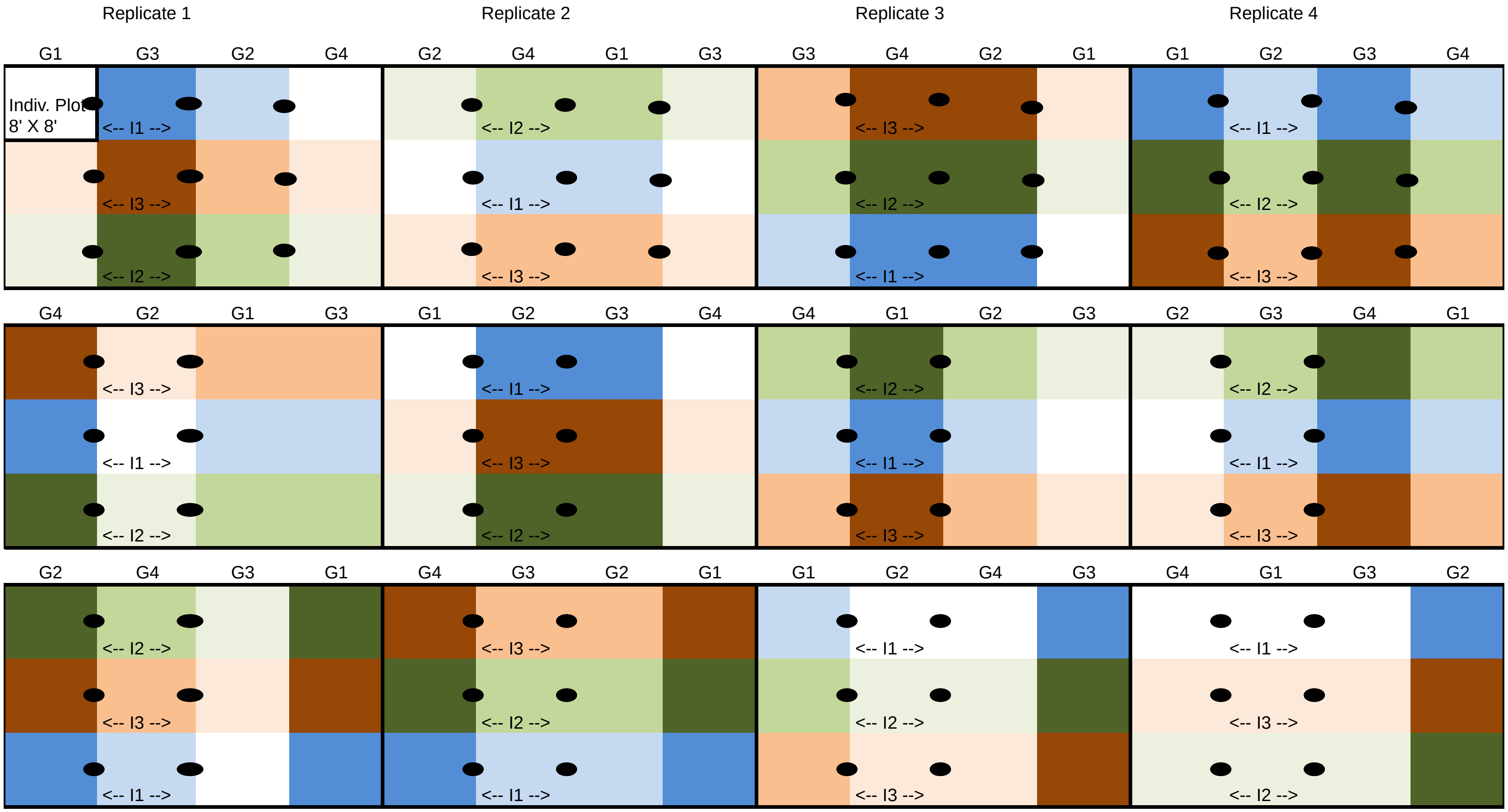
Day	Cycles (#)	Runtime (min)	Amount (mm)	Total (mm)	Cumulative (mm)	Time (hr)
1	3	6	3.8	11.4	11.4	5, 9, 16
2	3	6	3.8	11.4	22.9	5, 9, 16
3	3	6	3.8	11.4	34.3	5, 9, 16
4	3	6	3.8	11.4	45.7	5, 9, 16
5	3	6	3.8	11.4	57.2	5, 9, 16
6	2	9	5.1	10.2	67.3	9, 16
7	2	9	5.1	10.2	77.5	9, 16
8	2	9	5.1	10.2	87.6	9, 16
9	2	9	5.1	10.2	97.8	9, 16
10	2	9	5.1	10.2	108.0	9, 16
11	1	19	10.2	10.2	118.1	8
12	1	19	10.2	10.2	128.3	8
13	1	19	10.2	10.2	138.4	8
14	1	19	10.2	10.2	148.6	8
15	1	19	10.2	10.2	158.8	8
16	1	19	12.7	12.7	171.5	8
17					171.5	
18	1	19	12.7	12.7	184.2	8
19					184.2	
20	1	19	12.7	12.7	196.9	8
21					196.9	
22	1	19	12.7	12.7	209.6	8
23					209.6	
24	1	19	12.7	12.7	222.3	8
25					222.3	
26	1	19	12.7	12.7	235.0	8
27					235.0	
28	1	19	12.7	12.7	247.7	8
29					247.7	
30	1	19	12.7	12.7	260.4	8

Table 2-3. 30-30 establishment irrigation schedule.

Day	Cycles (#)	Runtime (min)	Amount (mm)	Total (mm)	Cumulative (mm)	Time (hr)
1	3	6	3.8	11.4	11.4	5, 9, 16
2	3	6	3.8	11.4	22.9	5, 9, 16
3	3	6	3.8	11.4	34.3	5, 9, 16
4	3	6	3.8	11.4	45.7	5, 9, 16
5	3	6	3.8	11.4	57.2	5, 9, 16
6	3	6	3.8	11.4	68.6	5, 9, 16
7	3	6	3.8	11.4	80.0	5, 9, 16
8	3	6	3.8	11.4	91.4	5, 9, 16
9	3	6	3.8	11.4	102.9	5, 9, 16
10	3	6	3.8	11.4	114.3	5, 9, 16
11	2	9	5.1	10.2	124.5	9, 16
12	2	9	5.1	10.2	134.6	9, 16
13	2	9	5.1	10.2	144.8	9, 16
14	2	9	5.1	10.2	154.9	9, 16
15	2	9	5.1	10.2	165.1	9, 16
16	2	9	5.1	10.2	175.3	9, 16
17	2	9	5.1	10.2	185.4	9, 16
18	2	9	5.1	10.2	195.6	9, 16
19	2	9	5.1	10.2	205.7	9, 16
20	2	9	5.1	10.2	215.9	9, 16
21	1	19	10.2	10.2	226.1	8
22	1	19	10.2	10.2	236.2	8
23	1	19	10.2	10.2	246.4	8
24	1	19	10.2	10.2	256.5	8
25	1	19	10.2	10.2	266.7	8
26	1	19	10.2	10.2	276.9	8
27	1	19	10.2	10.2	287.0	8
28	1	19	10.2	10.2	297.2	8
29	1	19	10.2	10.2	307.3	8

Table 2-3. Continued

Day	Cycles (#)	Runtime (min)	Amount (mm)	Total (mm)	Cumulative (mm)	Time (hr)
30	1	19	12.7	12.7	320.0	8
31					320.0	
32	1	19	12.7	12.7	332.7	8
33					332.7	
34	1	19	12.7	12.7	345.4	8
35					345.4	
36	1	19	12.7	12.7	358.1	8
37					358.1	
38	1	19	12.7	12.7	370.8	8
39					370.8	
40	1	19	12.7	12.7	383.5	8
41					383.5	
42	1	19	12.7	12.7	396.2	8
43					396.2	
44	1	19	12.7	12.7	408.9	8
45					408.9	
46	1	19	12.7	12.7	421.6	8
47					421.6	
48	1	19	12.7	12.7	434.3	8
49					434.3	
50	1	19	12.7	12.7	447.0	8
51					447.0	
52	1	19	12.7	12.7	459.7	8
53					459.7	
54	1	19	12.7	12.7	472.4	8
55					472.4	
56	1	19	12.7	12.7	485.1	8
57					485.1	
58	1	19	12.7	12.7	497.8	8
59					497.8	
60	1	19	12.7	12.7	510.5	8



tion treatment rows will be randomized in each replicate as shown.
will be randomized in columns in each planting.
Tentative soil sample location for soil water holding capacity and textural analysis

I1 period 1	I2 per 1	I3 per1
I1 period 2	I2 per 2	I3 per2
I1 period 3	I2 per 3	I3 per3

Figure 2-1. Plot plan showing irrigation treatment and grass locations (G1, Empire Zoysia; G2, Floratam St. Augustine; G3, Captiva St. Augustine; G4, Argentine, Bahia) for all three planting seasons.

CHAPTER 3
RESULTS

Weather

The project site received a total of 316.2 cm of rainfall during the study period (16 June 2011 through 5 Nov 2013) from 289 separate rainfall events (Figure 3-1); 66% of the study period contained dry days. Rainfall events ranged in amount from 0.03 to 11.1 cm per event with a median rainfall rate of 0.3 cm and a mean of 1.1 cm. Five out of the six establishment periods occurred during months that were drier than historical averages. However, the second summer establishment occurred during higher than historical average rainfall months. Seasonal temperatures ranged from 65 to 96°F (summer establishment), 46 to 92°F (fall establishment), and 30 to 86°F (winter establishment) (Figure 3-2) and were generally consistent with historical conditions.

Irrigation

Irrigation applied differed between establishment treatments for the first 60 days (Table 3-1). When irrigation amounts were averaged across all seasons, the 30-30 treatment resulted in the highest amount of irrigation applied (497.8 mm). The 15-15 treatment resulted in the second highest amount of irrigation applied (363.2 mm) with the NON treatment resulting in the lowest amount of irrigation applied (213.4 mm). There were no differences in irrigation between treatments during days 61-300. This was expected considering after the 60 d establishment period all treatments were on the same irrigation regime. Specific irrigation amounts applied for each season are in Table 3-2. For the post establishment monitoring period of the summer establishment for year one, days 61 to 300, the irrigation amounts applied should have been the same for all treatments, however, due to equipment failure that resulted in changing out all nozzles, the amounts applied varied slightly

Visual Ratings

‘Argentine’ Bahiagrass

During the summer establishment period of year 1 and increase in irrigation during the first 90 d showed to have a positive effect on turfgrass quality (Table 3-3). Form 0-30 d, the 30-30 and 15-15 treatments resulted in higher turfgrass quality (4.8 and 4.5 respectively) than the NON treatment (4.1). For 31-90 d, the 30-30 treatment resulted in higher turfgrass quality than both the 15-15 and NON treatments. After 90 d there were no differences in quality between irrigation treatments. For the summer establishment of year 2 irrigation had no effect on visual quality. The reduced rainfall in year 1 compared to year 2 could have impacted the effect of the irrigation treatments during the first summer establishment.

During the fall establishment period for both years there were no differences in turfgrass quality between any of the irrigation treatments at any time.

During the winter establishment period of year 1 there were no differences in turfgrass quality between irrigation treatments at any time. For the winter establishment of year 2 there was a slight increase in turfgrass quality with an increase in irrigation. From 31-60 d the 30-30 and 15-15 treatments resulted in higher turfgrass quality (4.6 and 4.5 respectively) than the NON treatment (4.1). After 60 d there were no differences in turfgrass quality between irrigation treatments.

‘Captiva’ St. Augustinegrass

On average year 2 resulted in higher visual quality ratings than year 1 for all seasons and irrigation treatments (Figure 3-3). For the summer of year 1, the 30-30 irrigation treatment resulted in higher visual quality (5.2) than both the 15-15 and NON irrigation treatments (4.2 and 3.5 respectively). The reduced rainfall during the first summer compared to the second and the presence of disease during the first summer resulted in quality levels that were below the minimally acceptable level of 5.0. There were no differences between irrigation treatments for fall or winter seasons. Qian and Engleke (1999), also found that increased irrigation did not affect the visual quality of St. Augustinegrass.

Differences in visual quality between irrigation treatments over time for each season were observed (Figure 3-4). During the summer, for days 0-30, the 30-30 and 15-15 treatments resulted in higher average visual quality (6.4 and 5.9 respectively) than the NON treatment (5.3). For days 31-180, the 30-30 treatment resulted in higher average visual quality than both the 15-15 and NON irrigation treatments. After this time there were no differences in visual quality between irrigation treatments. For the fall and winter, there were no differences in visual quality between the irrigation treatments for each time period.

'Floratam' St. Augustinegrass

During the summer of year 1, both the 30-30 and 15-15 irrigation treatments resulted in higher visual quality (5.3 and 5.3 respectively) than the NON irrigation treatment (4.5) (Figure 3-5). Similar to the first summer, both the 30-30 and 15-15 irrigation treatments resulted in higher visual quality (4.8 and 4.6 respectively) than the NON treatment (3.5), during the second summer. During both summer establishments Floratam had take-all root rot disease issues that affected the quality of the turfgrass. For the fall and winter of both years, there were no differences in visual quality between irrigation treatments and the winter establishment resulted in the highest visual quality ratings.

Differences in visual quality between irrigation treatments over time for each season (Figure 3-6). For days 0-30 during the summer, the 15-15 treatment resulted in higher visual quality (6.1) than the NON treatment (5.1). For days 31-300, both the 30-30 and 15-15 treatments resulted in higher visual quality than the NON irrigation treatment, except for days 211-240, where there were no differences between treatments. Similar to findings from Qian and Engleke (1999), an increase in irrigation did not affect the quality of Floratam during the fall and winter establishments of this study.

‘Empire’ zoysiagrass

For the first summer, the 30-30 irrigation treatment resulted in higher visual quality (6.0) than both the 15-15 and NON irrigation treatments (5.7 and 5.3 respectively) (Figure 3-7). Fu et al. (2004), found that when irrigating with higher amounts zoysiagrass maintained acceptable quality, even during drought stress. There were no differences between treatments for any of the remaining seasons.

Digital Image Analysis

‘Argentine’ Bahiagrass

On average year 2 resulted in higher percent green cover than year 1 for all irrigation and compaction treatment combinations (Figure 3-8). For year 1, the 30-30 un-compacted treatment resulted in the highest percent green cover (41.4%). There were no differences in percent green cover for the other irrigation and compaction treatment combinations for year 1, even though a bulk density level of 1.7 g cm^{-3}, similar to construction sites, was achieved. For year 2, there were no differences in percent green cover between any of the irrigation and compaction treatment combinations.

There were differences in percent green cover between irrigation treatments over time for each season (Figure 3-9). During summer establishment, there were no differences in percent green cover between any of the irrigation treatments for any time period. During the fall establishment, for days 61-90, the 30-30 treatment resulted in higher average percent green cover (56.8%) than the 15-15 treatment (48%). For days 91-120 the 30-30 treatment resulted in higher average percent green cover (49.5%) than both the 15-15 and NON irrigation treatments (41.2 and 42.2% respectively). The higher irrigation treatment resulted in longer lasting green turfgrass as the fall establishment period was growing into winter months. During the winter, for days 31-60, both the 30-30 and 15-15 treatments resulted in higher average percent green cover (30 and 27.3% respectively) than the NON treatment (20.2%). For days 61-90, the 30-30 treatment resulted in higher average percent green cover (46.3%) than the NON treatment (35.2%), however, neither treatment was statistically different than the 15-15 treatment (42.2%). Similarly, Qian and Engleke (1999) found that increased irrigation resulted in faster spring green up of warm-season turfgrasses in their study.

‘Captiva’ St. Augustinegrass

On average, year 2 resulted in higher percent green cover than year 1 for all seasons and irrigation treatments (Figure 3-10). During the first summer, the 30-30 treatment resulted in higher percent green cover than both the 15-15 and NON treatments. This could have also been affected by the take-all root rot disease that was experience during late summer of year 1. There were no differences in percent green cover between all irrigation treatments for the remaining seasons.

On average year 2 resulted in higher percent green cover than year 1 for all seasons and compaction treatments (Figure 3-11). For both years, there were no differences in percent green cover between compaction treatments for each individual season. Summer and fall establishment of year 1 was also affected by take-all root rot disease and subsequently resulted in the lowest percent green cover compared to all other seasons.

There were differences in percent green cover between irrigation treatments over time for each season (Figure 3-12). For days 0-30 during the summer, both the 30-30 and 15-15 treatments resulted in higher percent green cover (67.9 and 61.6% respectively) than the NON treatment (52%). For days 31-60 during the summer, the 30-30 treatment resulted in higher percent green cover (68%) than the 15-15 or NON treatments (54 and 51% respectively). During the first 60 days of both summer establishment periods there were times when rainfall was below the historical average, which could have led to a reduction in the percent green cover as plots were experiencing some drought stress. For the fall and winter, there were no differences in percent green cover between any of the irrigation treatments for each time period. The winter had on average the highest percent green cover compared to the summer and fall for most time periods.

‘Floratam’ St. Augustinegrass

On average for both years the winter resulted in higher percent green cover than the summer or fall for all irrigation treatments (Figure 3-13). For year 1, there were no differences in percent green cover between irrigation treatments for each individual season. For the summer of year 2, both the 30-30 and 15-15 treatments resulted in higher percent green cover (42.1 and 40% respectively) than the NON treatment

(31.6%). For the fall and winter of year 2, there were no differences in percent green cover between irrigation treatments.

On average for both years the turfgrass established during winter resulted in higher percent green cover than the summer or fall for all compaction treatments (Figure 3-14). For both years, there were no differences in percent green cover between compaction treatments for each individual season. The summer of year 1, resulted in the lowest percent green cover overall, regardless of compaction treatment, which could have been affected by the take-all root rot disease that was diagnosed and treated for this season.

There were differences in percent green cover between irrigation treatments over time for each season (Figure 3-15). For days 0-30 during the summer, both the 30-30 and 15-15 treatments resulted in higher percent green cover (53.7 and 57.4% respectively) than the NON treatment (39.4%). For days 31-60, the 30-30 treatment resulted in higher percent green cover (57.9) than the NON treatment (45.5%). During the first 60 days of both summer establishment periods there were times when rainfall was below the historical average, which could have led to a reduction in the percent green cover as plots were experiencing some drought stress. For the fall and winter, there were no differences in percent green cover between any of the irrigation treatments for each time period.

‘Empire’ Zoysiagrass

On average for both years the winter establishment period had higher percent green cover than the summer or fall for both compaction treatments (Figure 3-16). For both years, there were no differences in percent green cover between compaction treatments within each individual season. The winter of year 2, resulted in the highest percent green cover overall, regardless of compaction treatment. Summer and fall establishment of year 1 was also affected by take-all root rot disease and subsequently resulted in the lowest percent green cover compared to all other seasons.

There were differences in percent green cover between irrigation treatments over time for each season (Figure 3-17). For the first 60d of establishment during the fall and summer, the 30-30 treatment resulted in higher percent green cover than the NON treatment. For days 31-60 during the winter, the 30-30 treatment had higher percent green cover (49.6%) than the NON treatment (37.7%). Qian and Engleke (1999) found that as irrigation is increased the ability of zoysiagrass to increase in green cover was also increased. For all seasons, there were no further differences in percent green cover between irrigation treatments beyond 60d.

Root Growth Response

‘Argentine’ Bahiagrass

The mean total root length at the different sampling depths was affected by soil compaction. At the 0-7.5 cm depth, there were no differences in total root length. For both the 7.5-15 cm depth and the 15-30 cm depth, the un-compacted treatment resulted in greater total root length compared to the compacted treatment (Figure 3-18). This is not unexpected since it is known that compacted soils can impede root growth (Steinke et al., 2010)

The mean total root length for each year was affected by the compaction treatments. Specifically, for year 1 the un-compacted treatment resulted in greater total root length than the compacted treatment. There were no differences between treatments for year 2 (Figure 3-19). Ishaq (2001) found that when wheat was grown on the same land two years in a row, compaction did not have any effect on root growth for the second year.

‘Captiva’ St. Augustinegrass

The mean total root length was greater for the un-compaction treatment during year 1. In year 2 there were no differences in total root length due to compaction treatments (Figure 3-20).

The mean total root length was greater during the winter establishment period compared to the summer or fall. For the summer and winter establishment periods, there were no differences in mean total root length between compaction treatments. For the fall, the un-compacted soil resulted in higher mean total root length (113.3 cm) than the compacted soil (73.4 cm) (Figure 3-21). This is not unexpected since it is known that compacted soils can impede root growth (Steinke et al., 2010). The mean total root length was greatest for the un-compacted soil treatment at the 0-7.5 cm depth (175.5 cm) (Figure 3-22).

‘Floratam’ St. Augustinegrass

There were no significant differences in mean total root length between any treatments (data not presented). In other studies, irrigation frequency also had no effect on the root growth of St. Augustinegrass (Peacock and Dudeck, 1984; Sinclair et al., 2011).

‘Empire’ Zoysiagrass

The mean total root length was greater for the un-compacted treatment (128.3 cm) than the compacted treatment (100.3 cm). This is not unexpected since it is known that compacted soils can impede root growth (Steinke et al., 2010) (Figure 3-23).

Table 3-1. Average Irrigation applied during and after establishment periods.

Treatment	Establishment Irrigation Days 0-60	Maintenance Irrigation Days 61-300	Total Irrigation Days 0-300
		mm	
30-30 Establishment Irrigation	497.8a*	769.6a	1267.4
15-15 Establishment Irrigation	363.2b	754.4a	1117.6
No Establishment Irrigation	213.4c	716.3a	929.7

*Values within a column with the same letter are not significantly different at the 0.05 level by Tukey's HSD.

Table 3-2. Irrigation applied and rainfall amounts (in mm) for each treatment during each season.

Planting Date	Treatment	Irrigation Days 0-60	Rainfall Days 0-60	Water Input Days 0-60	Irrigation Days 61-300	Rainfall Days 61-300	Water Input Days 61-300	Irrigation Days 0-300	Rainfall Days 0-300	Water Input Days 0-300
					mm					
					2011					
Summer	15-15*	375.9	414.0	789.9	1160.8	810.3	1971.1	1536.7	1224.3	2761.0
	30-30†	459.7	414.0	873.8	975.4	810.3	1785.7	1435.1	1224.3	2659.4
	NON‡	269.2	414.0	683.3	1132.8	810.3	1943.1	1402.1	1224.3	2626.4
Fall	15-15	381.0	157.5	538.5	838.2	538.5	1376.7	1219.2	696.0	1915.2
	30-30	426.7	157.5	584.2	787.4	538.5	1325.9	1214.1	696.0	1910.1
	NON	304.8	157.5	462.3	812.8	538.5	1351.3	1117.6	696.0	1813.6
Winter	15-15	406.4	38.1	444.5	723.9	1046.5	1770.4	1130.3	1084.6	2214.9
	30-30	622.3	38.1	660.4	726.4	1046.5	1772.9	1348.7	1084.6	2433.3
	NON	221.0	38.1	259.1	726.4	1046.5	1772.9	947.4	1084.6	2032.0
					2012					
Summer	15-15	309.9	518.2	828.1	619.8	629.9	1249.7	929.6	1148.1	2077.7
	30-30	472.4	518.2	990.6	571.5	629.9	1201.4	1043.9	1148.1	2192.0
	NON	215.9	518.2	734.1	609.6	629.9	1239.5	825.5	1148.1	1973.6
Fall	15-15	363.2	188.0	551.2	571.5	756.9	1328.4	934.7	944.9	1879.6
	30-30	452.1	188.0	640.1	556.3	756.9	1313.2	1008.4	944.9	1953.3
	NON	172.7	188.0	360.7	574.0	756.9	1331.0	746.8	944.9	1691.6
Winter	15-15	345.4	30.5	375.9	696.0	1204.0	1899.9	1041.4	1234.4	2275.8
	30-30	551.2	30.5	581.7	678.2	1204.0	1882.1	1229.4	1234.4	2463.8
	NON	104.1	30.5	134.6	670.6	1204.0	1874.5	774.7	1234.4	2009.1

* Irrigation every day for 15 days, every other day for 15 days

† Irrigation every day for 30 days, every other day for 30 days

‡ No additional establishment irrigation (once or twice per week irrigation dependent on time of year)

Table 3-3. Irrigation effect over time for each season of each year on visual quality of ‘Argentine’ bahiagrass.

	Days After Planting									
Irrigation Treatment	0-30	31-60	61-90	91-120	121-150	151-180	181-210	211-240	241-270	271-300
					Year 1					
					Summer					
15-15	4.5a*	5.2b	48.b	5.4	5.6	5.3	5.4	5.0	5.2	5.2
30-30	4.8a	6.0a	5.6a	5.6	5.6	5.3	5.5	5.0	5.1	5.2
NON	4.1b	4.9b	4.7b	5.2	5.3	5.4	5.6	4.9	5.2	5.3
					Fall					
15-15	4.2	6.3	6.2	5.8	5.1	5.1	5.6	5.6	6.3	6.6
30-30	4.2	6.5	6.7	6.1	5.4	5.3	5.8	6.1	6.7	6.8
NON	4.1	6.1	6.2	6.0	5.0	5.3	5.5	5.0	6.3	6.8
					Winter					
15-15	2.5	3.9	5.2	4.7	4.3	5.1	5.9	6.0	5.7	5.8
30-30	2.5	3.9	5.3	5.0	4.6	5.3	6.0	6.0	5.7	5.8
NON	2.5	3.5	5.1	4.5	4.6	5.1	6.1	6.0	5.8	5.9
					Year 2					
					Summer					
15-15	4.5	5.6	5.9	5.9	6.2	6.1	6.4	5.5	5.4	5.5
30-30	4.5	5.8	6.0	6.1	6.4	6.1	6.2	5.5	5.3	5.5
NON	4.5	5.3	5.8	5.8	6.3	5.9	6.3	5.5	5.4	5.4
					Fall					
15-15	4.6	5.5	6.0	6.1	6.0	6.0	5.3	6.4	6.6	6.9
30-30	4.6	5.7	6.2	6.1	6.0	6.0	5.5	6.6	6.4	6.9
NON	4.5	5.5	5.8	6.0	6.0	5.8	5.3	6.3	6.4	6.8
					Winter					
15-15	3.7	4.5a	4.8	5.5	6.2	6.3	6.0	6.0	6.5	6.1
30-30	3.6	4.6a	4.8	5.4	6.0	6.3	5.9	6.0	6.5	6.1
NON	3.6	4.1b	4.6	5.3	5.9	6.7	6.1	6.0	6.4	6.1

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*Values within a column with different letters are significantly different at a p value of 0.05 as determined by Tukey multiple comparison procedure.

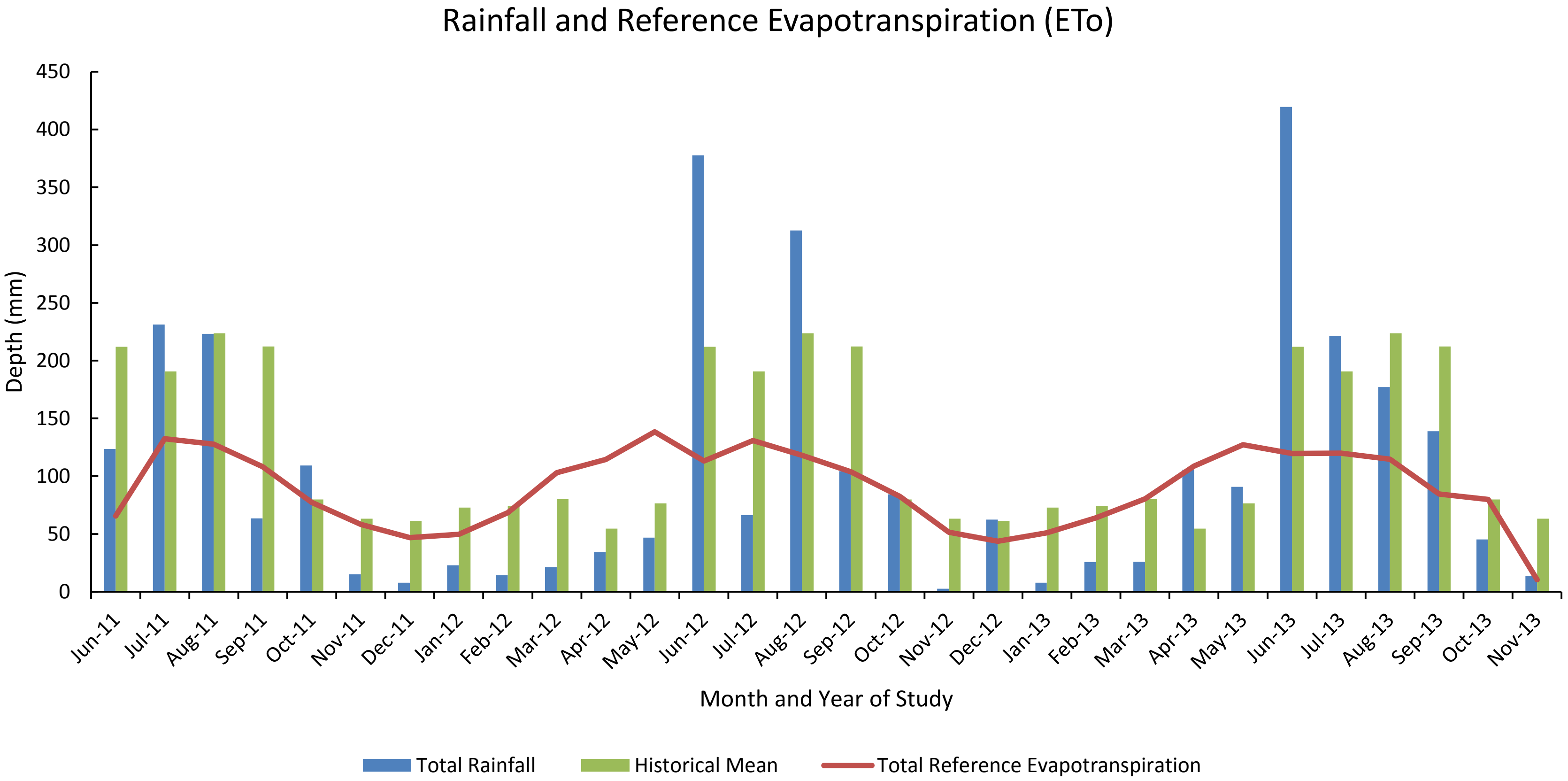

Figure 3-1. Monthly rainfall, historical mean rainfall, and reference evapotranspiration for the entire study period beginning 16 June 2011 and ending 5 Nov 2013, for Balm, FL.

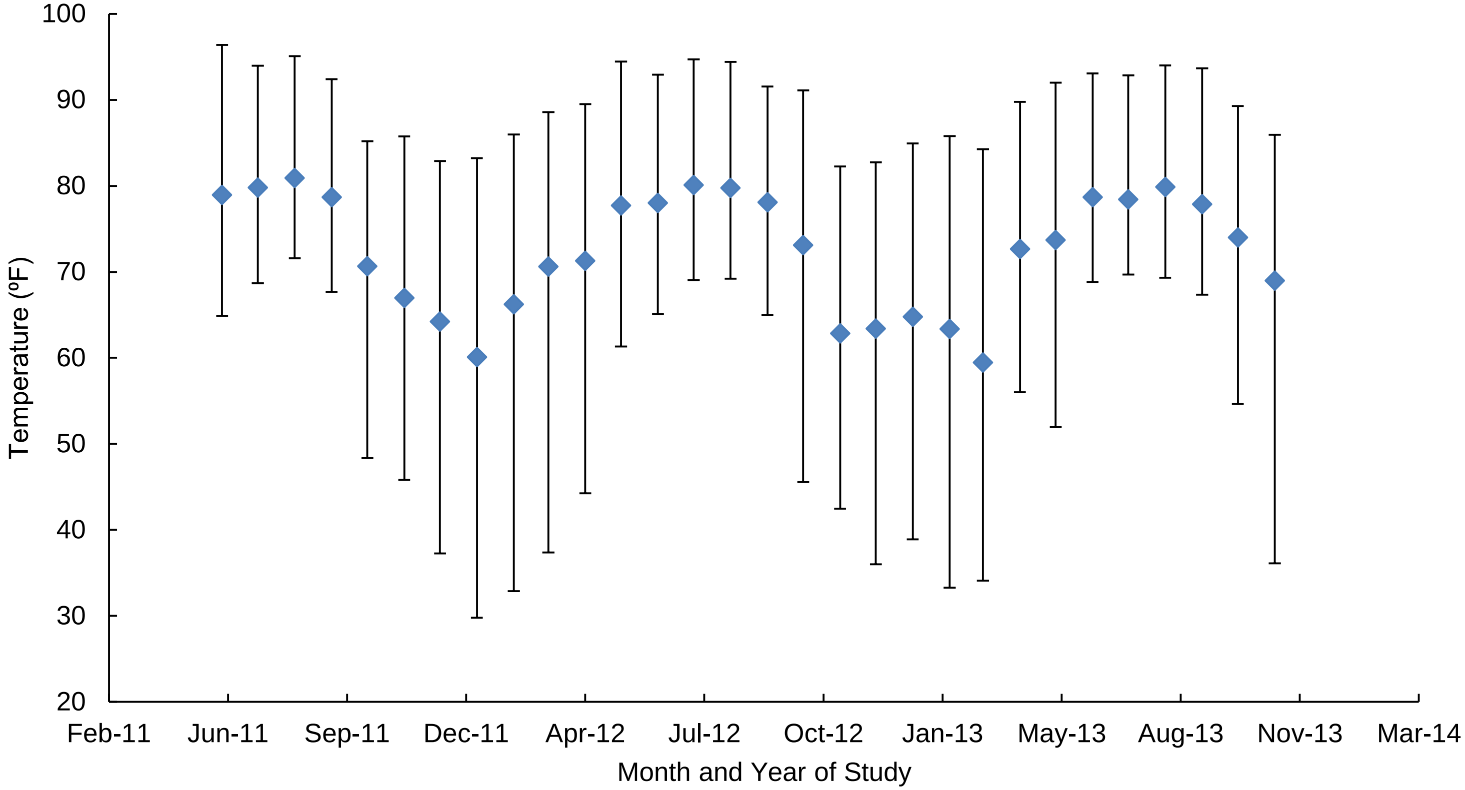

Figure 3-2. Monthly temperatures for the entire study period beginning 16 June 2011 and ending 5 Nov. 2013, for Balm, FL. The blue diamonds represent average monthly temperature, while the upper and lower bars represent the average maximum and minimum monthly temperatures.

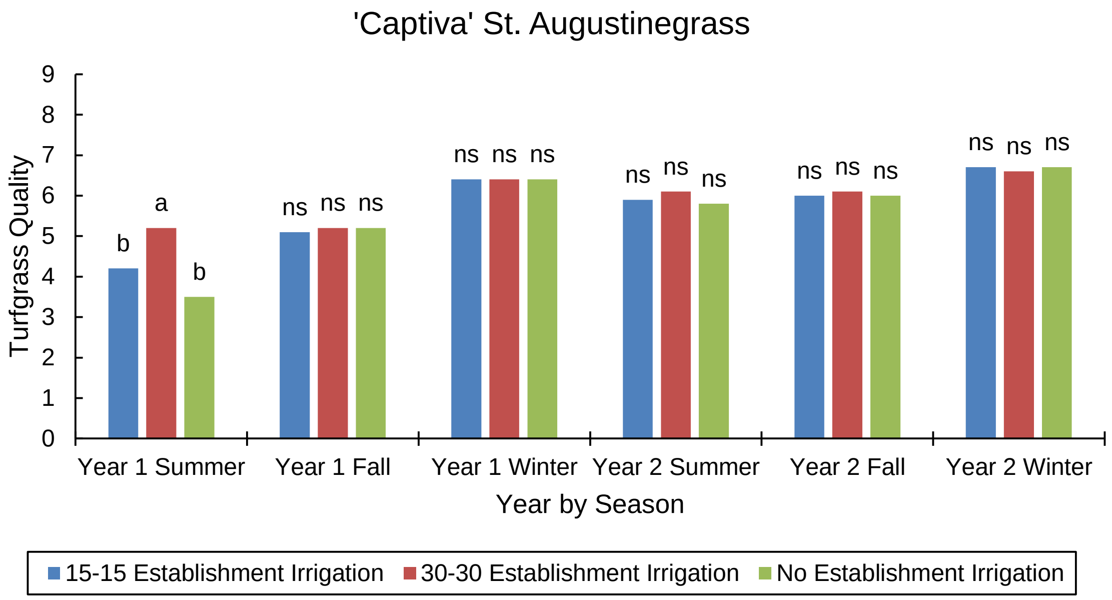

Figure 3-3. Year by Season by Irrigation effect on visual quality of ‘Captiva’ St. Augustinegrass averaged over the 300 day monitoring period. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters indicate differences between means and “ns” indicates no differences between means within each three-column group as determined by Tukey’s multiple comparison test.

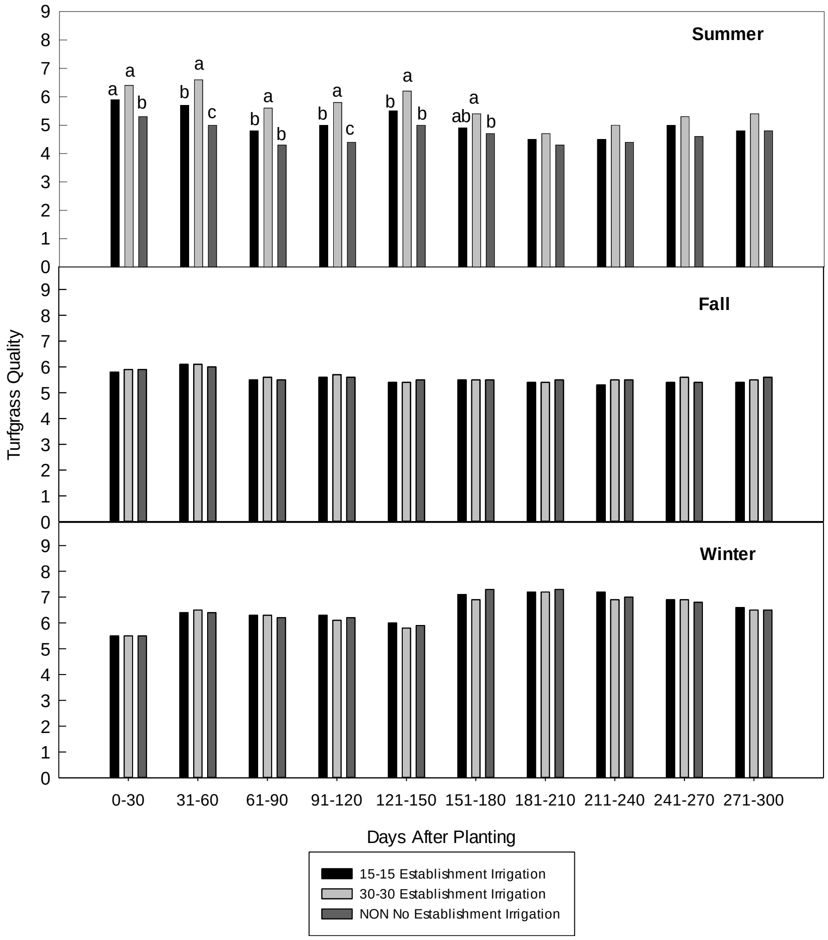

Figure 3-4. Season by time by irrigation effect on visual quality of ‘Captiva’ St. Augustinegrass averaged over both years for each season. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters indicate differences between means and “ns” indicates no differences between means within each three-column group as determined by Tukey’s multiple comparison test.

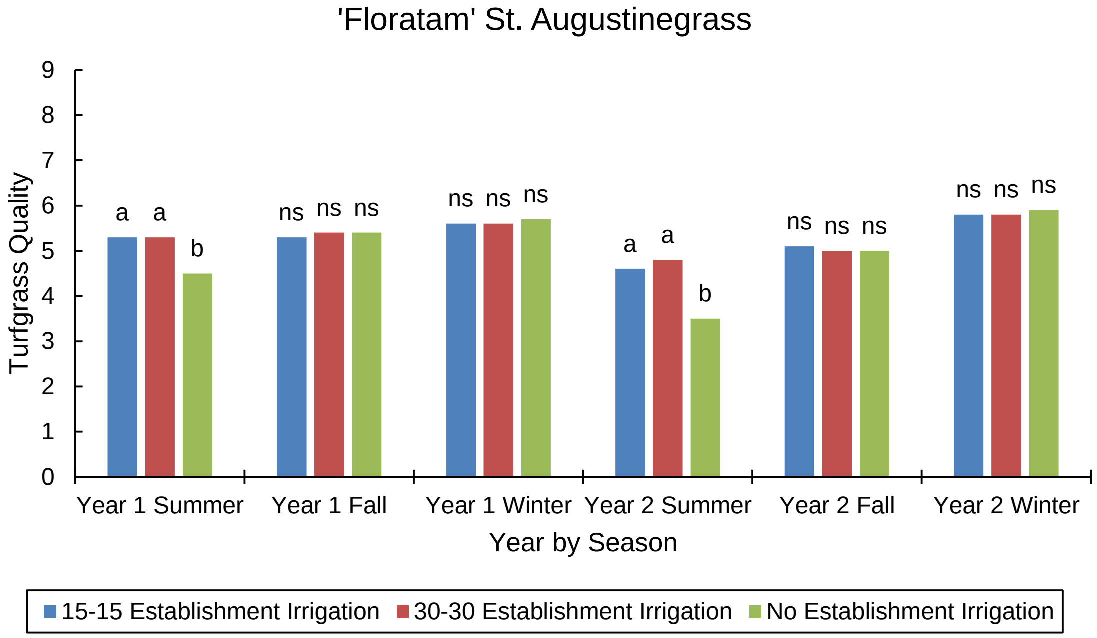

Figure 3-5. Year by Season by Irrigation effect on visual quality of ‘Floratam’ St. Augustinegrass averaged over the 300 day monitoring period. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters indicate differences between means and “ns” indicates no differences between means within each three-column group as determined by Tukey’s multiple comparison test.

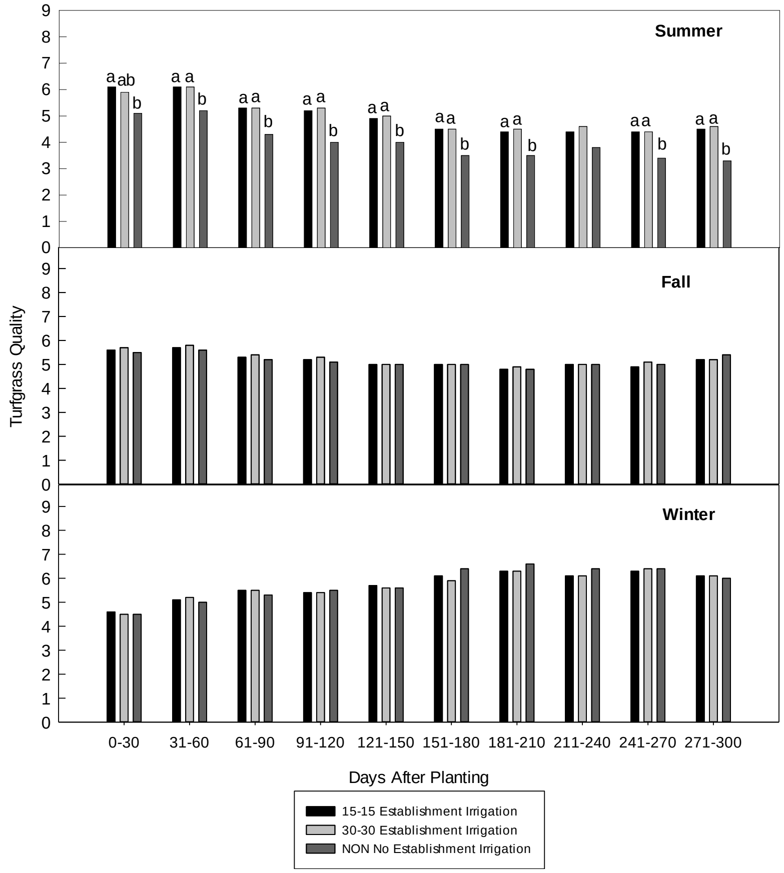

Figure 3-6. Season by time by irrigation effect on visual quality of 'Floratam' St. Augustinegrass averaged over both years for each season. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters indicate differences between means and "ns" indicates no differences between means within each three-column group as determined by Tukey's multiple comparison test.

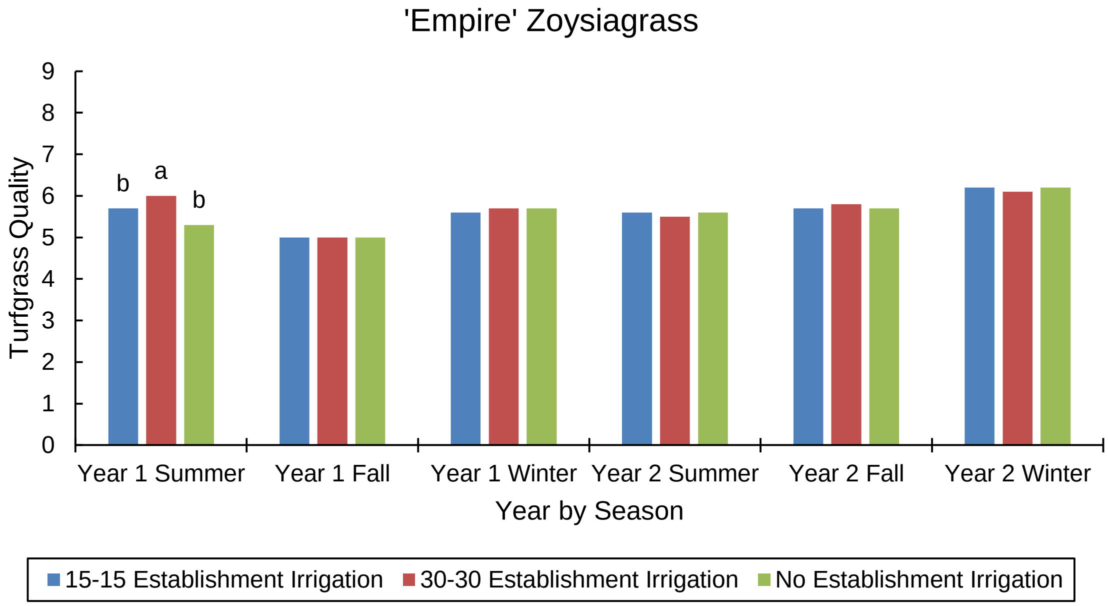

Figure 3-7. Year by Season by Irrigation effect on visual quality of 'Empire' zoysiagrass averaged over the 300 day monitoring period. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters indicate differences between means between means within each three-column group as determined by Tukey's multiple comparison test.

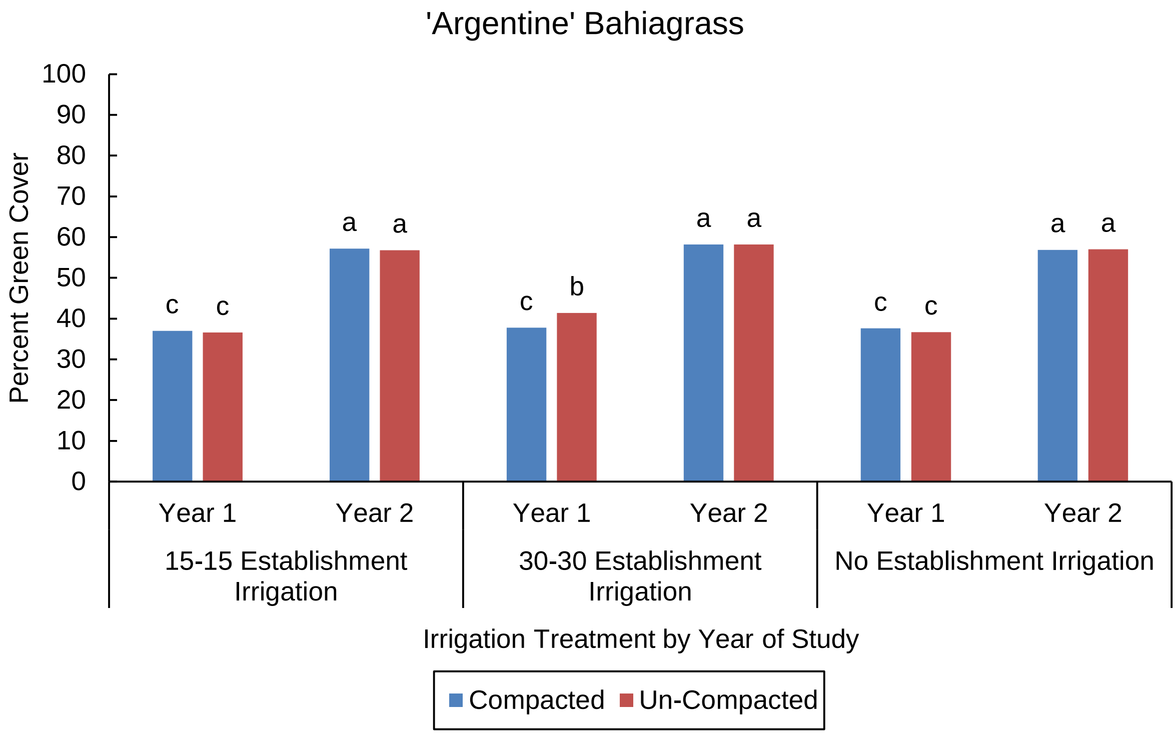

Figure 3-8. Year by irrigation by compaction effect of the percent green cover of ‘Argentine’ bahiagrass averaged across all seasons. Establishment irrigation treatments consist of 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters above columns indicate differences between means between all columns as determined by Tukey’s multiple comparison test.

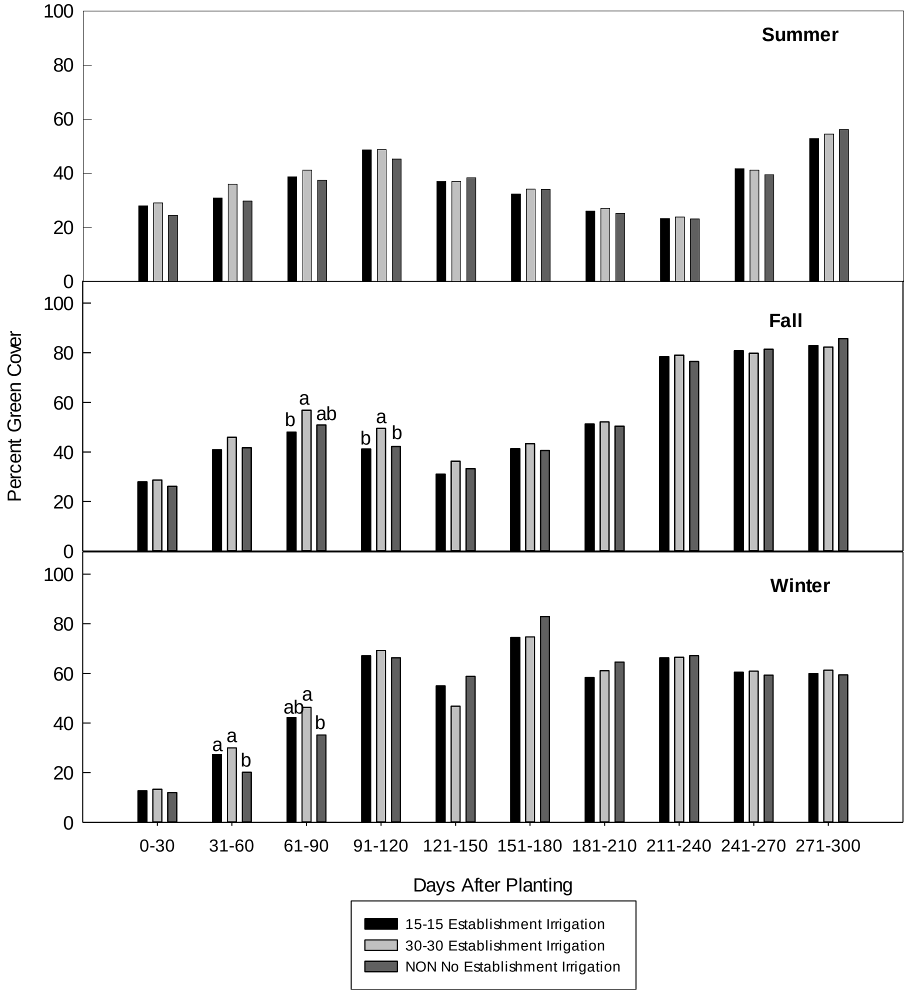

Figure 3-9. Season by time by irrigation effect on percent green cover of ‘Argentine’ bahiagrass averaged over both years for each season. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters indicate differences between means and “ns” indicates no differences between means within each three-column group as determined by Tukey’s multiple comparison test.

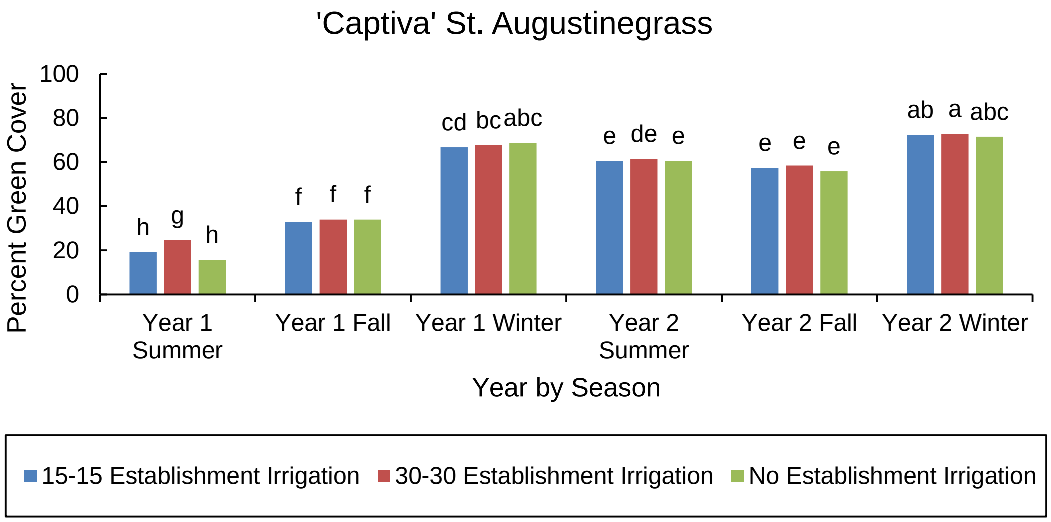

Figure 3-10. Year by Season by Irrigation effect on percent green cover of ‘Captiva’ St. Augustinegrass averaged over the 300 day monitoring period. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters above columns indicate differences between means within each three-column group as determined by Tukey’s multiple comparison test

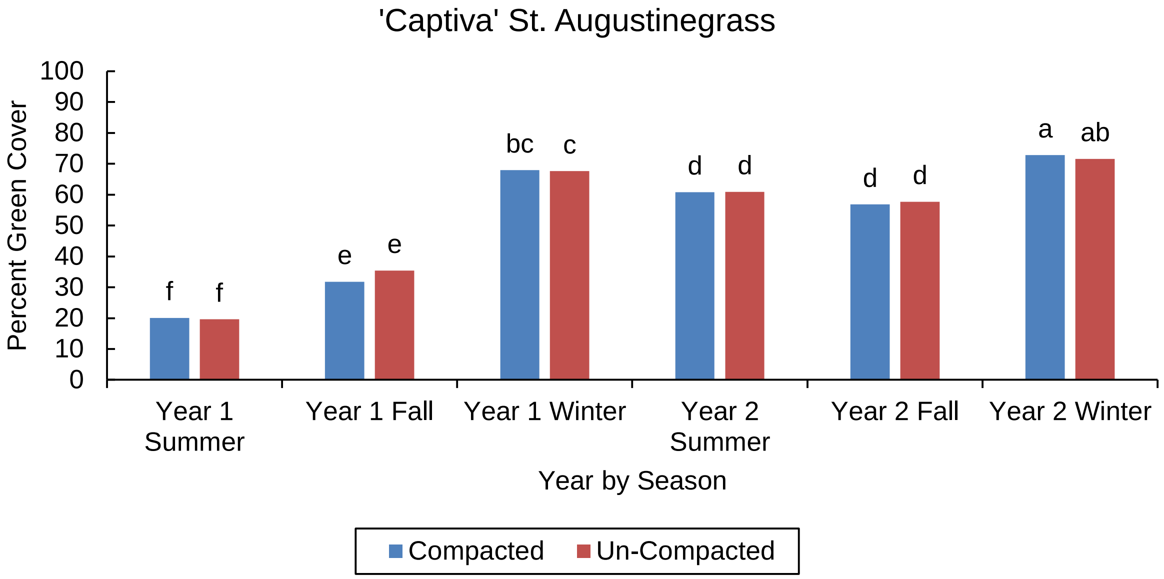

Figure 3-11. Year by Season by compaction effect on percent green cover of 'Captiva' St. Augustinegrass averaged over the 300 day monitoring period. Different letters above columns indicate differences between means for all columns as determined by Tukey's multiple comparison test.

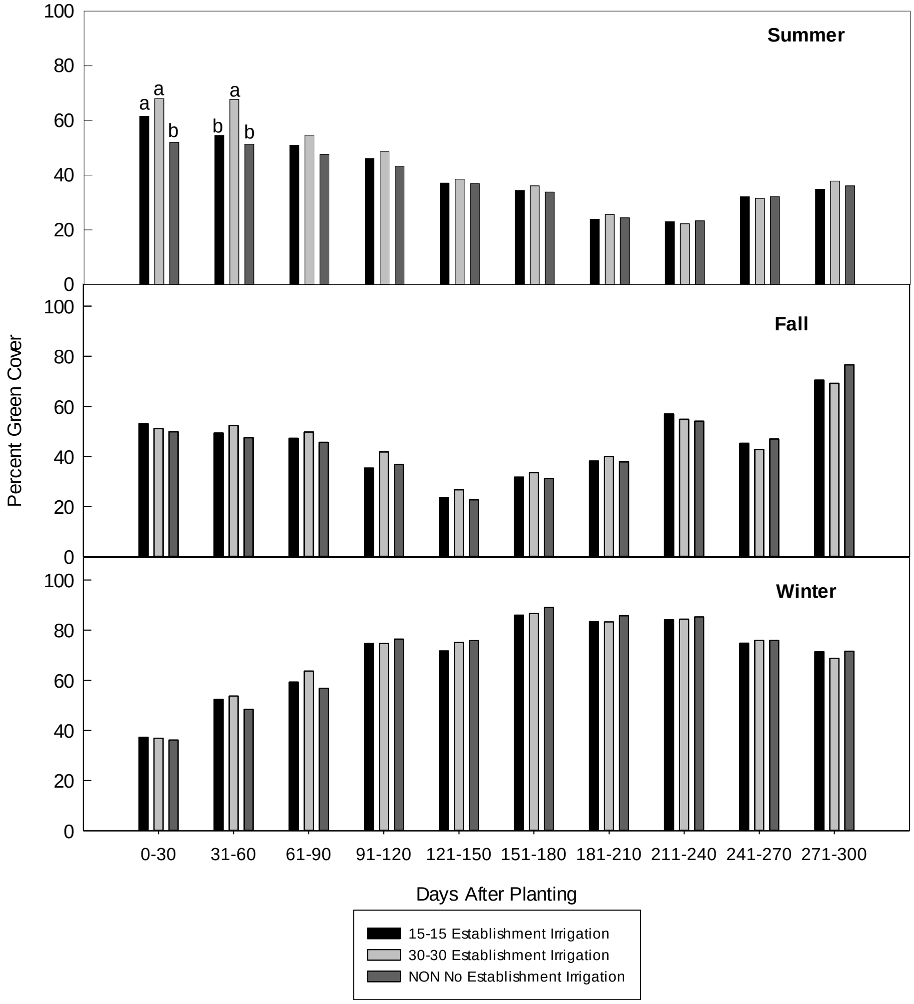

Figure 3-12. Season by time by irrigation effect on percent green cover of 'Captiva' St. Augustinegrass averaged over both years for each season. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters indicate differences between means and "ns" indicates no differences between means within each three-column group as determined by Tukey's multiple comparison test.

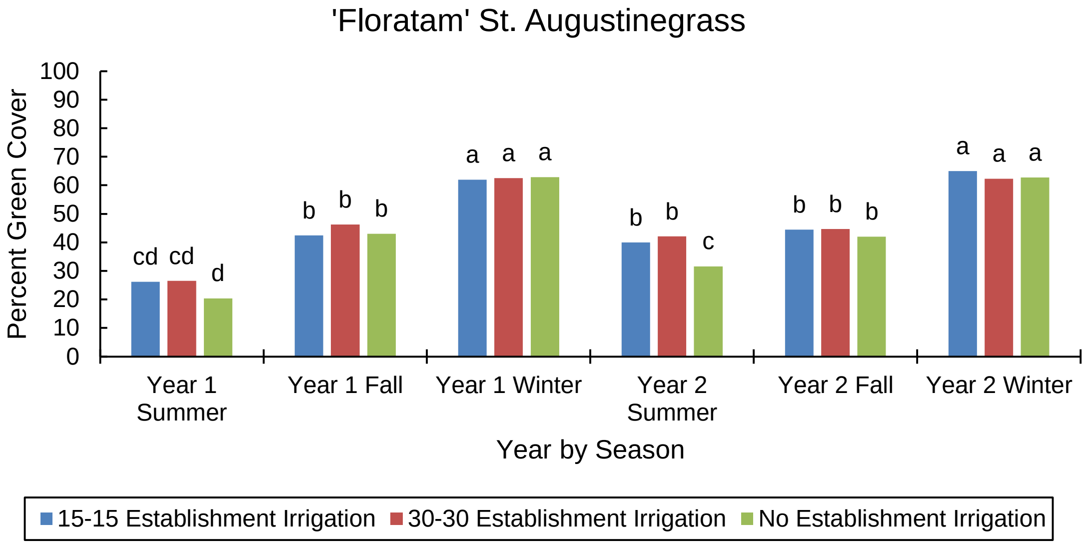

Figure 3-13. Year by Season by Irrigation effect on percent green cover of ‘Captiva’ St. Augustinegrass averaged over the 300 day monitoring period. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters above columns indicate differences between means for all columns as determined by Tukey’s multiple comparison test.

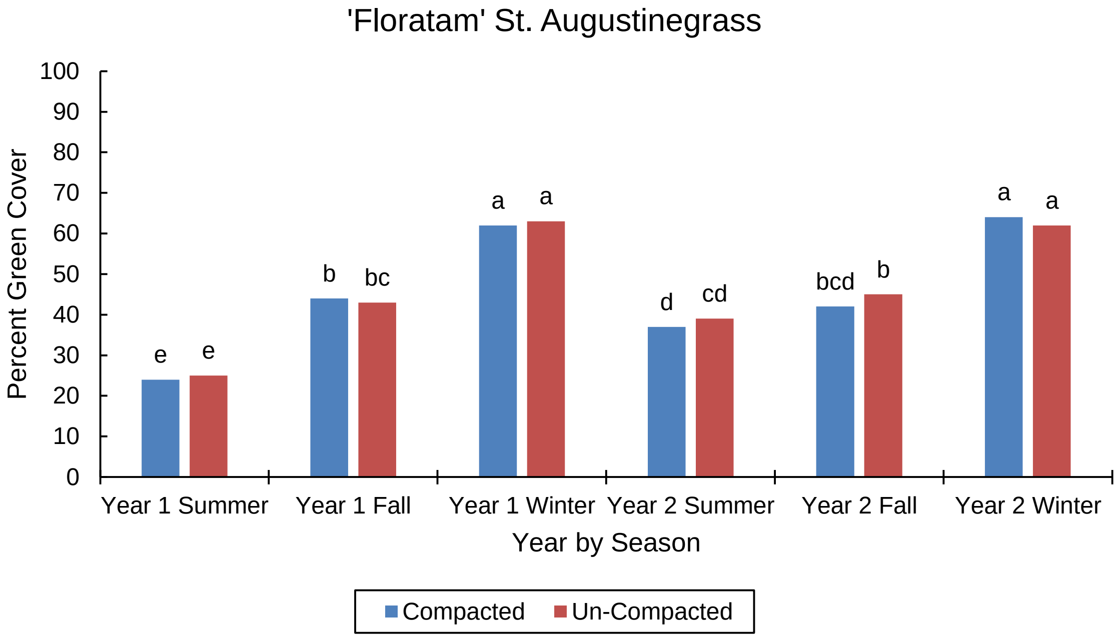

Figure 3-14. Year by Season by compaction effect on percent green cover of ‘Floratam’ St. Augustinegrass averaged over the 300 day monitoring period. Different letters above columns indicate differences between means for all columns as determined by Tukey’s multiple comparison test.

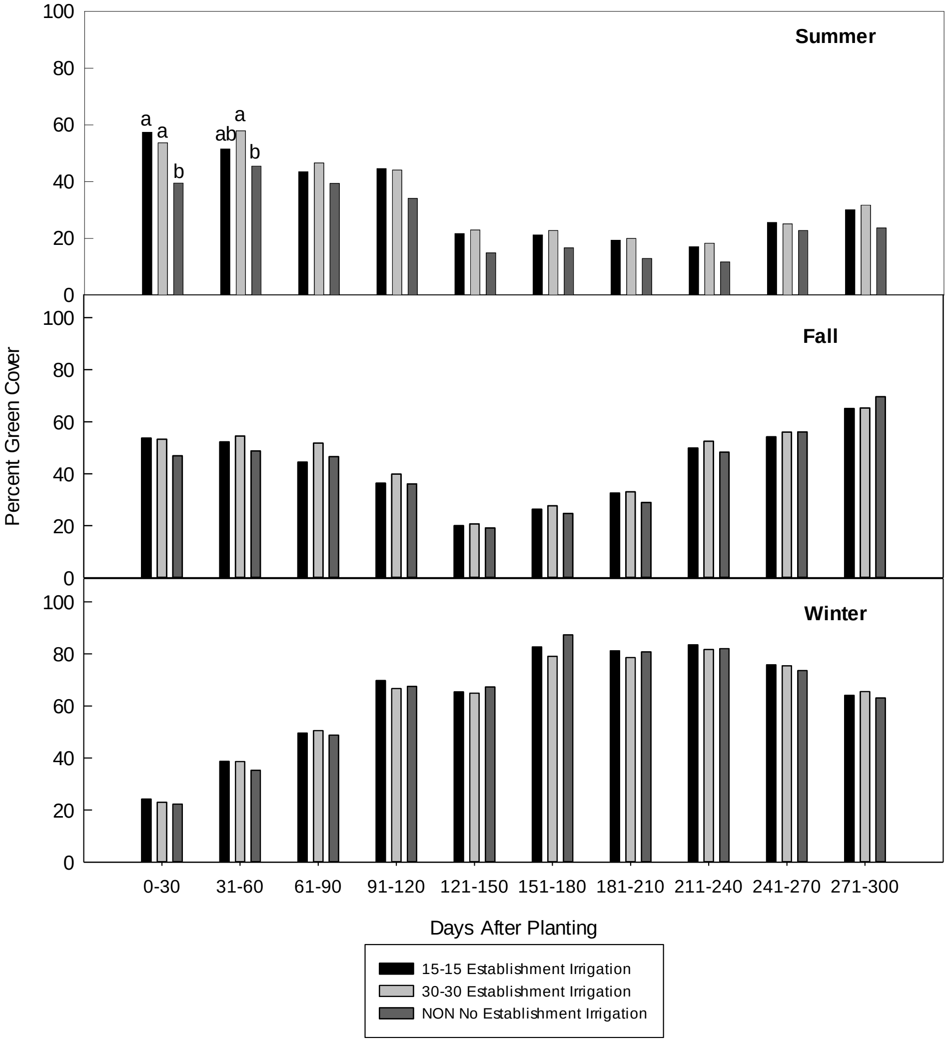

Figure 3-15. Season by time by irrigation effect on percent green cover of ‘Floratam’ St. Augustinegrass averaged over both years for each season. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters indicate differences between means and “ns” indicates no differences between means within each three-column group as determined by Tukey’s multiple comparison test.

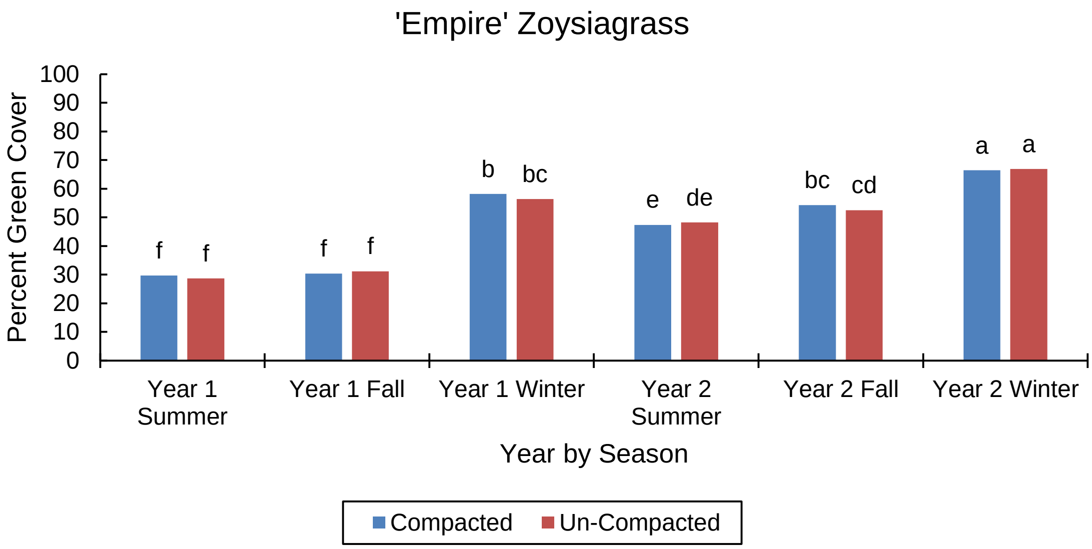

Figure 3-16. Year by Season by compaction effect on percent green cover of ‘Empire’ zoysiagrass averaged over the 300 day monitoring period. Different letters above columns indicate differences between means for all columns as determined by Tukey’s multiple comparison test.

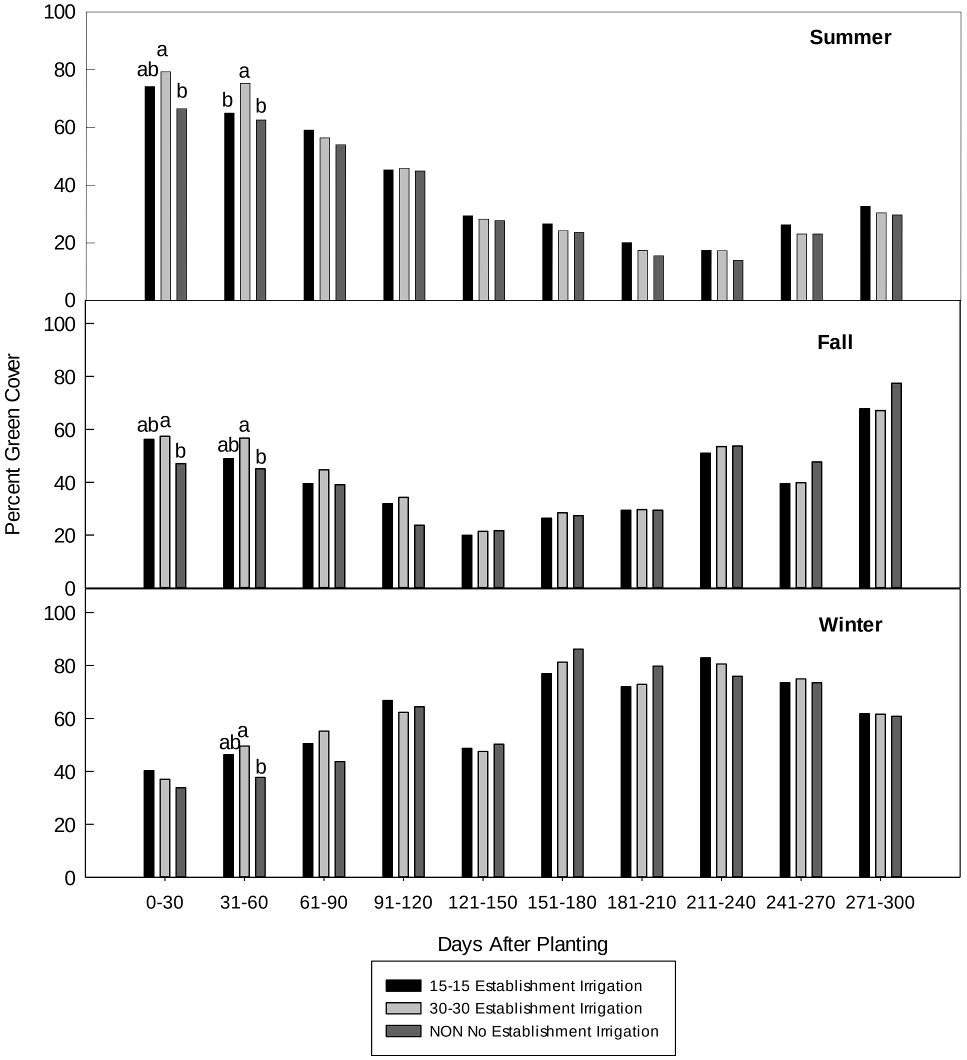

Figure 3-17. Season by time by irrigation effect on percent green cover of 'Empire' zoysiagrass averaged over both years for each season. Establishment irrigation treatments are 15-15 (daily irrigation for 15 days, every other day for 15 days); 30-30 (daily irrigation for 30 days, every other day for 30 days); and NON (no establishment irrigation, irrigated two times per week Mar.-Nov. and once per week Dec.-Feb.). Different letters indicate differences between means and "ns" indicates no differences between means within each three-column group as determined by Tukey's multiple comparison test.

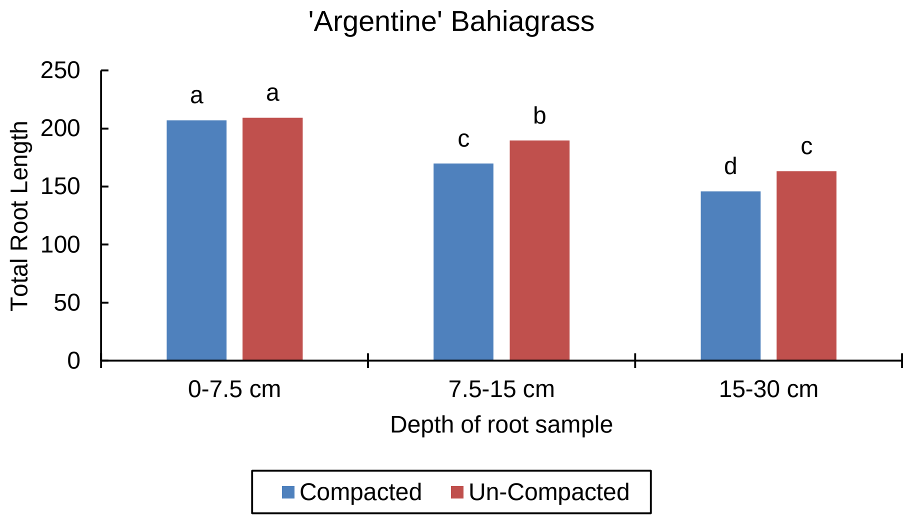

Figure 3-18. Influence of compacted soils at three different rooting depths on total root length (cm) for ‘Argentine’ Bahiagrass averaged over all seasons for both years. Different letters above columns indicate differences between means for all columns as determined by Tukey’s multiple comparison test.

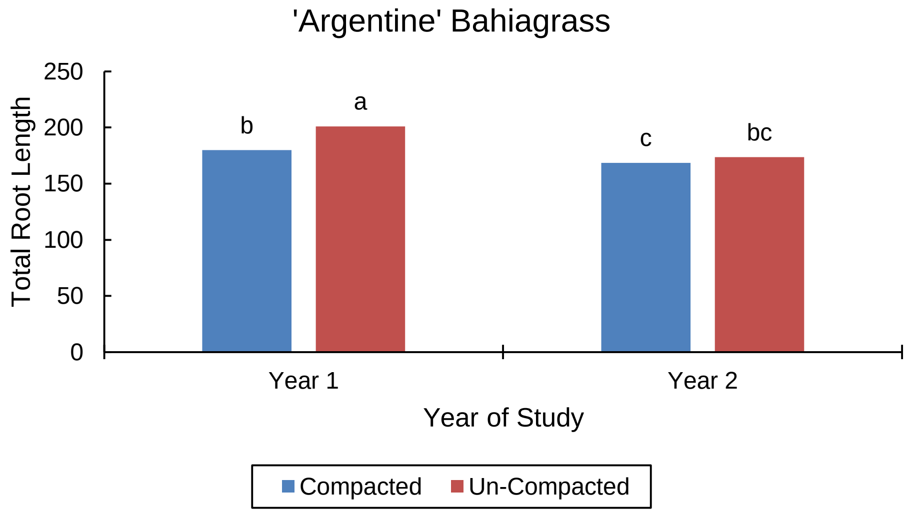

Figure 3-19. Influence compacted soils for averaged over all seasons for each year on total root length (cm) for ‘Argentine’ Bahiagrass. Different letters above columns indicate differences between means for all columns as determined by Tukey’s multiple comparison test.

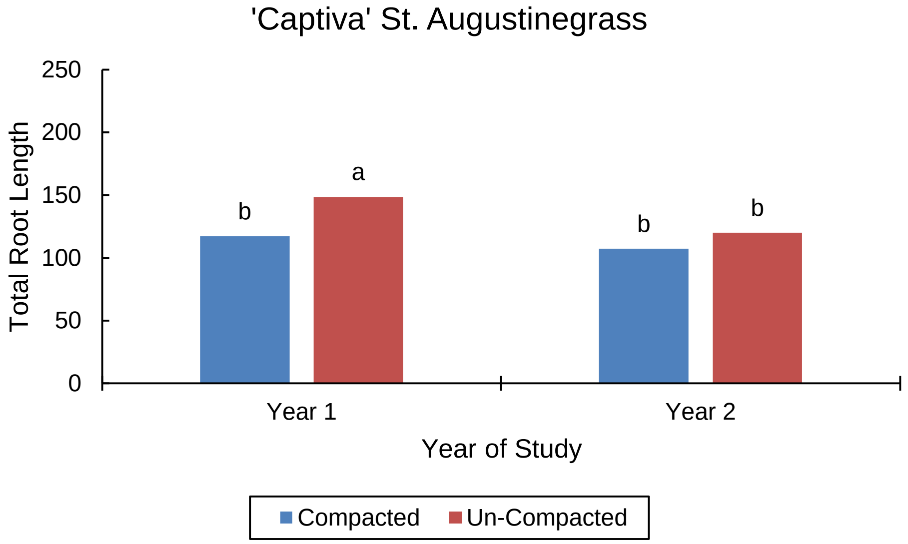

Figure 3-20. Influence compacted soils for each year on total root length (cm) for ‘Captiva’ St. Augustinegrass averaged over the entire 300 day monitoring period for all three seasons for each year. Different letters above columns indicate differences between means for all columns as determined by Tukey’s multiple comparison test.

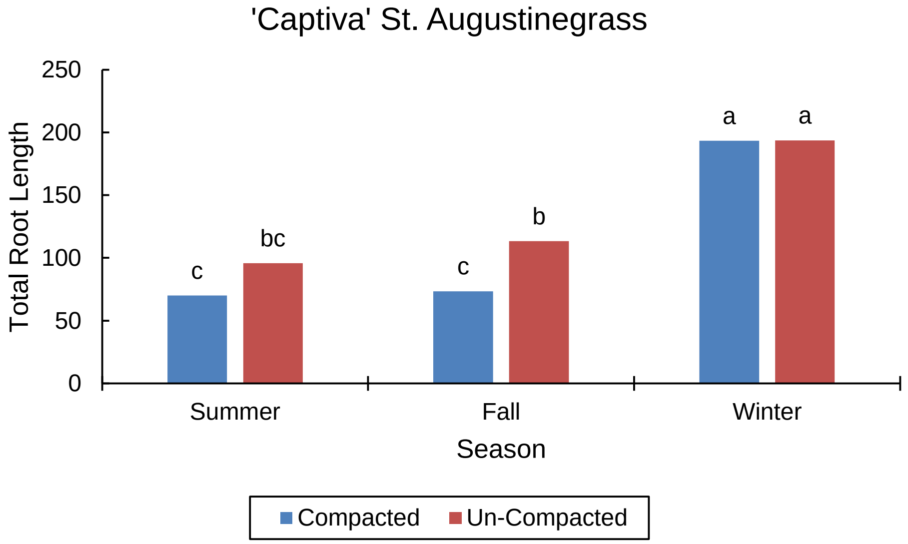

Figure 3-21. Influence compacted soils for each season on total root length (cm) for ‘Captiva’ St. Augustinegrass. Different letters above columns indicate differences between means for all columns as determined by Tukey’s multiple comparison test.

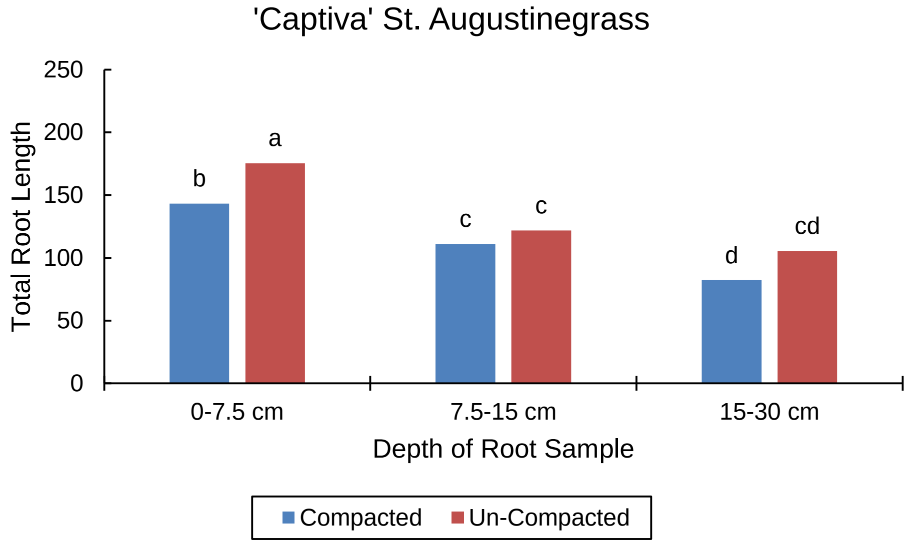

Figure 3-22. Influence compacted soils for each rooting depth on total root length for ‘Captiva’ St. Augustinegrass. Different letters above columns indicate differences between means for all columns as determined by Tukey’s multiple comparison test.

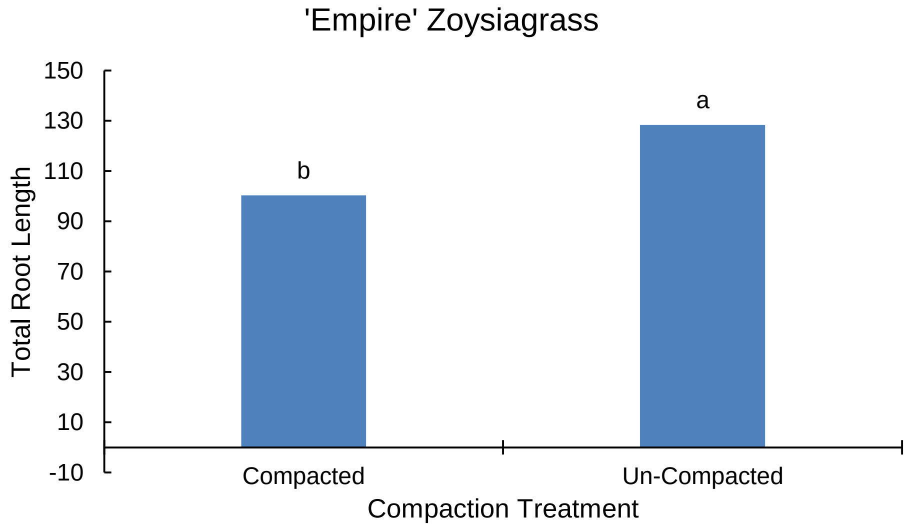

Figure 3-23. Influence of compaction on the total root length (cm) of ‘Empire’ zoysiagrass averaged across all seasons for both years. Different letters indicate differences between means as determined by Tukey’s multiple comparison test.

CHAPTER 4
CONCLUSIONS

It was hypothesized that a 30 d establishment irrigation period (15-15 irrigation treatment) would be sufficient to successfully establish warm-season turfgrass sod. When establishing Floratam during the summer, the 15-15 irrigation treatment resulted in acceptable turfgrass quality. However, for zoysiagrass, when establishing during the summer, the 30-30 irrigation treatment resulted in the highest quality level, but, the 15-15 treatment was still at an acceptable turfgrass quality. Captiva establishment during the summer was acceptable under the 30-30 treatment during year 1 and the 15-15 treatment during year 2. Bahiagrass had slightly higher quality during the first summer establishment under the 30-30 irrigation treatment for the first 90 d. However, for the second summer, bahiagrass was successfully established under the NON irrigation treatment.

During the first summer establishment period there was a take-all root rot disease problem that had an effect on the overall quality of all grasses. The first summer establishment experienced lower than historical rainfall for the first 30 d followed by slightly higher than historical rainfall for the second 30 d. On the other hand, the second summer establishment had higher than historical rainfall for the first 30 d followed by 30 d of normal rainfall levels. A 15-15 establishment irrigation regime would work for establishing all grasses during the summer. However, in situations outside the conditions of this study there could be potential for failure when establishing bahiagrass or Captiva.

For any of the grasses established in the summer, by using the 15-15 treatment instead of the 30-30 treatment during establishment, a 26% water savings is possible, under the conditions of this study. Fu et al. (2004) was able to maintain acceptable turfgrass quality with irrigation as low as 17 mm wk^{-1}. The 15-15 treatment plots were irrigated at 40 mm wk^{-1} during the 60 d summer establishment period.

During a fall establishment bahiagrass, Captiva, Floratam, and zoysiagrass were all established to an acceptable quality regardless of irrigation treatment under the conditions of this study. When compared to the 30-30 treatment, the 15-15 and NON irrigation treatments resulted in 11% and 29% reduction in water, respectively. Under the NON irrigation treatment plots received an average of 28 mm wk^{-1}during the 60 d establishment period. Previous work shows that turfgrasses are able to maintain acceptable quality when irrigated between 17 mm wk^{-1} and 41 mm wk^{-1} (Fu et al., 2004; Wherley, 2011). While the NON irrigation treatment received no addition establishment irrigation it still applied enough water during establishment to maintain acceptable turfgrass quality. During the fall of both years rainfall was below historical averages for the first month but normal for the second month of the 60 d establishment period. While the NON treatment led to a successful establishment of all grasses, during a drier year the 15-15 treatment would be a more secure option for establishing sod.

During a winter establishment Captiva, Floratam, and Zoysiagrass were all established to an acceptable quality regardless of irrigation treatment under the conditions of this study. Bahiagrass established successfully regardless of irrigation treatment for the winter establishment of year 1, however for the time period of 31-60 d during the year 2 winter establishment the increased irrigation had higher quality than the NON treatment. However, after 60 d there were no other differences between treatments on the turfgrass quality. Because there were no other effects on visual quality using the NON treatment for the winter establishment would be sufficient. When compared to the 30-30 treatment, the 15-15 and NON irrigation treatments resulted in 36% and 73% reduction in water, respectively. Under the NON irrigation treatment plots received an average of 19 mm wk^{-1}during the 60 d establishment period. Previous work shows that turfgrasses are able to maintain acceptable quality when irrigated between 17 mm wk^{-1} and 41 mm wk^{-1} (Fu et al., 2004; Wherley, 2011). While the NON irrigation treatment received no addition establishment irrigation it still applied enough water during establishment to maintain acceptable turfgrass quality. Because winter rainfall was below the historical average during the 60 d establishment period, a recommendation of no establishment irrigation can be made when laying sod in Southwest Florida in Jan.

A change in bulk density from 1.6 g cm^{-3} to 1.7 g cm^{-3} had a negative effect on root growth for three of the grasses in this study. Bahiagrass had an 11% reduction in total root length at a soil depth of 7.5 cm to 30 cm, while Captiva had an 18 % reduction in total root length in the top 7.5 cm of soil as a result of compaction. Zoysiagrass experienced a 22% reduction in total root length when planted on compacted soils. Floratam had no changes in root growth due to compaction throughout the study. Previous research has shown that small changes in bulk density can have a negative effect on root growth. For example, decreases in root growth were seen for Kentucky bluegrass when bulk density is increased from 1.27 g cm^{-3} to 1.32 g cm^{-3}, perennial ryegrass when bulk density is increased from 1.27 g cm^{-3} to 1.32 g cm^{-3}, tall fescue when bulk density is increased from 1.32 g cm^{-3} to 1.34 g cm^{-3}, St. Augustinegrass when bulk density is increased from 1.6 g cm^{-3} to 1.8 g cm^{-3}, and zoysiagrass, bermudagrass, and centipedegrass when bulk density is increased 1.8 to 1.9 g cm^{-3} (Carrow, 1980; Matthieu, 2011). Previous research in agronomic crops reported decreased root growth for barley when bulk density is increased from 1.64 g cm^{-3} to 1.78 g cm^{-3}, oats when bulk density is increased from 1.38 to 1.52 and wheat when bulk density is increased from 1.33 to 1.52 (Oussible et al., 1992; Shuurman, 1965).

Irrigation treatments had no effect on the total root length of any grasses in this study. It is thought that irrigation of new sod is critical to promote root growth, however, Sinclair et al. (2011) found that frequency of irrigation had no effect on root growth. They also found that for bahiagrass, zoysiagrass, and St. Augustinegrass only 13 mm wk^{-1} irrigation was sufficient for root growth of sod.

The NON treatment received, on average, as low as 19 mm wk^{-1} of irrigation during the establishment period, which has been shown to be enough to be successful in producing acceptable turfgrass quality in mature grasses. Many studies show that turfgrass is able to be irrigated below 100% ET and still maintain acceptable quality. Meyer and Gibeault (1986) found that warm season turfgrasses could maintain acceptable quality when irrigated at 43-63% of ET. Garrot and Mancino (1994) found that bermudagrass could be irrigated between 57 and 64% ET and still maintain acceptable quality. Carrow (1995) saw similar results with bermudagrass maintaining quality at 66% ET. He also found that zoysiagrass and St. Augustinegrass could maintain quality levels at 80 and 76% ET, respectively. Fu et al. (2004) found that bermudagrass and zoysiagrass were able to maintain acceptable quality at 60 and 80% ET, respectively. While these rates are primarily for mature turfgrass stands, Sinclair et al. (2011) found that successful sod establishment is possible under a modest, infrequent deficit irrigation regime when established on soil columns in a greenhouse environment. Since treatments during this study were never under severe drought stress during the 60 d establishment period, it could be beneficial to test even less frequent irrigation regimes on the establishment of warm-season turfgrass sod.

APPENDIX
SAMPLE TABLE OF EFFECTS OF FIXED VARIABLES

Table A-1. Effect of fixed variables and their interactions for turfgrass qualtity of bahiagrass.

Effect	Numerator DF	Denominator DF	F Value	Pr > F
Year	1	4319	357.96	<0.0001
Season	2	10.04	66.24	<0.0001
Year*Season	2	4319	30.34	<0.0001
Irrigation	2	65.67	19.6	<0.0001
Year*Irrigation	2	4319	4.32	0.0133
Season*Irrigation	4	65.77	1.67	0.1683
Year*Season*Irrigation	4	4319	2.70	0.0289
Compaction	1	65.67	0.58	0.4491
Year*Compaction	1	4319	0.00	0.9797
Season*Compaction	2	65.75	2.19	0.1205
Year*Season*Compaction	2	4319	1.44	0.2379
Irrigation*Compaction	2	61.77	0.80	0.4548
Year*Irrigation*Compaction	2	4319	0.21	0.8128
Season*Irrigation*Compaction	4	46.69	0.21	0.9311
Time	9	4319	579.91	<0.0001
Year*Time	9	4319	24.01	<0.0001
Season*Time	18	4319	90.73	<0.0001
Year*Season*Time	18	4319	19.46	<0.0001
Irrigation*Time	18	4319	2.28	0.0015
Year*Irrigation*Time	18	4319	0.57	0.9225
Season*Irrigation*Time	36	4319	1.05	0.3828
Compaction*Time	9	4319	0.82	0.6008
Year*Compaction*Time	9	4319	0.15	0.9981
Season*Compaction*Time	18	4319	0.68	0.8377
Irrigation*Compaction*Time	18	4319	0.22	0.9998

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BIOGRAPHICAL SKETCH

Natasha Restuccia was born and raised in Lakeland, FL. After graduating from the University of Florida in 2008, with her bachelor’s degree in turfgrass science she started working as a Lead Grounds worker for the Jacksonville Jaguars. Natasha enjoyed working at an NFL stadium, but, after three seasons she decided to pursue her master’s degree. While continuing her education at the University of Florida, Natasha has grown to love the research side of the turfgrass industry and hopes to pursue a career doing research.