Proc. Fla. State Hort. Soc. 121:340–345. 2008.

Effect of Irrigation Control on St. Augustinegrass Quality and Root Growth

Mary Shedd[1], Michael D. Dukes[1]*, and Grady L. Miller[2]

[1]*University of Florida, IFAS, Agricultural and Biological Engineering Department, Frazier Rogers Hall, PO Box 110570, Gainesville, FL 32611*

[2]*North Carolina State University, Crop Science Department, PO Box 7620, Raleigh, NC 27695*

Additional index words. *Stenotaphrum secundatum*

Due to water shortages, landscape irrigation is limited in many areas of Florida to 1 or 2 days per week. Three frequencies of irrigation on 'Floratam' St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze.] were evaluated based on root growth and turf quality. Six irrigation treatments were established using rain sensors set at rainfall thresholds of 3 and 6 mm and irrigation schedules of 1, 2, or 7 days per week. The volume applied per week was the same for all treatments. In addition there was a reduced irrigation treatment set for 2 days per week, with a 40% reduction in scheduled depth of application compared to the other treatments, a 2-day per week treatment without a rain sensor and a non-irrigated treatment. Root mass samples were taken once in 2006 and once in 2007 (15 cm and 30 cm). Analysis showed that frequency of irrigation did not have a significant impact on depth of root growth. The majority of the root mass was in the top 15 cm with 87% in 2006 and 75% in 2007. Turf quality was impacted by irrigation frequency, with 2 and 7 days of irrigation per week typically producing better quality than 1 day.

Water is required for the basic growth and maintenance of turfgrass and for sustaining a level of landscape quality desired by homeowners. Florida receives an average of 1300 mm of rainfall per year, but rainfall averages throughout the state vary, and the amount of rainfall during the year varies (Marella, 1992). In Florida, irrigation is necessary due to the sporadic nature of rainfall events and the low water holding capacity of the sandy soils present throughout the state. Higher water demands mean a need to increase the efficiency of current practices that require water. A better understanding of plant water needs, both the total volume and the timing of delivery, can lead to more efficient irrigation.

In Florida, there are five water management districts responsible for establishing regulations on water use, including irrigation, within each district. Landscape irrigation is regulated in most, if not all, areas in Florida. In the St. Johns River Water Management District (SJRWMD) irrigation is restricted to a maximum of 2 d/week between 4 pm and 10 am (SJRWMD, 2008). Kenney et al. (2004) conducted a study in Colorado to evaluate the effectiveness of day of the week irrigation restrictions at reducing water use during drought conditions. They found that mandatory watering restrictions along with distributing educational material reduced water use by 13% to 53%. The highest water savings were in cities where watering was limited to either 1 or 2 d/week (Kenney et al., 2004). However, anecdotal evidence suggests that even though day of the week irrigation restrictions reduce water use, over-irrigation can still occur due to the encouragement of watering during limited windows.

Proper irrigation practice is generally thought to be infrequent, deep applications of water in order to encourage deeper rooting of the grass. Rooting characteristics influence the amount of soil moisture available to a plant for growth. The amount of soil moisture available then affects the frequency of irrigation that is necessary for optimum plant response. Understanding the rooting characteristics of plants can assist in developing more effective and efficient irrigation practices (Peacock and Dudeck, 1985).

According to a study done by Doss et al. (1960), the rooting depth of five warm-season forage species decreased as soil moisture increased. The researchers also found that 76% of the roots on average were in the upper 30 cm (12 inches) of soil and 50% of the roots were in the upper 7.5 cm (3 inches). Peacock and Dudeck (1985) studied the rooting response of 'Floratam' St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze.] to varied irrigation intervals. The study was performed under field conditions with loamy siliceous hyperthermic Grosarenic Paleudult soil, similar to soil conditions present in our study. Root mass and root length were examined. Total irrigation volume per week was equal for all treatments; only irrigation frequency during the week was varied with irrigation intervals of 2, 3, 4, or 6 d. During two growing seasons no treatment effect was seen. Total root mass density decreased in the first season while in the second season root mass density increased for all treatments. In the first season over 40% of the root mass occurred below 30 cm (12 inches), while in the second season only 9% of the root mass was found below 30 cm (12 inches). Overall, the study found that the frequency of irrigation events had no effect on rooting depth or density.

Peacock and Dudeck (1984) examined the effect of frequency of irrigation on turf quality. The testing used irrigation intervals of 2, 3, 4, or 6 d to induce varying plant stress. Varying the interval between irrigation events had no effect on turfgrass quality and density.

The objectives of this experiment were to evaluate the differences in irrigation water application, rooting depth and turfgrass quality of St. Augustine turfgrass comparing irrigation scheduled for 1, 2, and 7 d per week and to correlate the presence of wilt in the turfgrass with corresponding soil VWC values.

*Corresponding author; email: mddukes@ufl.edu; phone: (352) 392-1864

Materials and Methods

Site description. This study was performed at the Plant Science Research and Education Unit in Citra, FL. There were four treatment periods: 22 Apr. to 30 June 2006 (S06), 23 Sept. to 15 Dec. 2006 (F06), 1 May to 31 Aug. 2007 (S07), and 1 Sept. to 30 Nov. 2007 (F07). In Aug. 2005, 'Floratam' St. Augustinegrass sod was laid in the center 1.8 m × 1.8 m (5.9 ft) of each 4.3 m × 4.3 m (14 ft) plot. The soil present is a loamy siliceous hyperthermic Grosarenic Paleudult soil.

Soil cores were collected on 11 Aug. 2006 using a device with a diameter of 54 mm and a length of 60 mm for soil physical properties analysis. Samples were collected in a total of 16 locations with four locations in each block. Soil samples were used to develop soil water retention curves according to methods described by Wraith and Or (1998) and to perform a particle size analysis according to methods described by Gee and Bauder (1986). Soil testing showed that the soil present at the field site consisted of 1.7% clay, 1.1% silt and 97.3% sand.

The field capacity (FC) values in the experimental field vary between 6% and 29% volumetric water content (VWC) and the permanent wilting point values (PWP) vary between 2% and 12% VWC. Both FC and PWP values increase moving across the field from west to east (moving from block 1 to block 4). Values for available water in each block, based on a 30-cm (12 inch) root zone, are shown in Fig. 1. Due to observed variations in soil moisture across the research site, treatments were arranged in a completely randomized block design. There were 72 plots with four blocks.

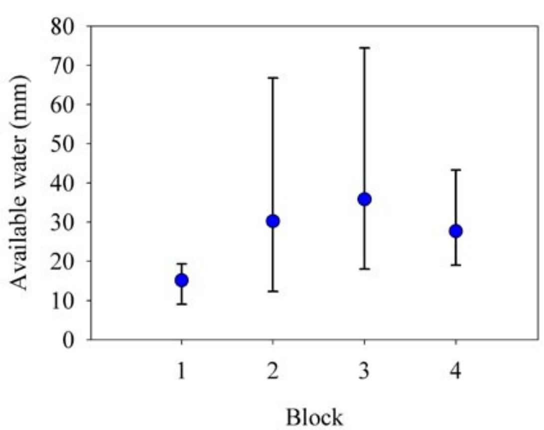

Fig. 1. Mean values for available water are shown for each block in the field based on a 30-cm (12 inch) root depth using circles. Bars show the maximum and minimum range of the values within in each block. Treatments were established in a randomized block design to account for inherent differences in soil water holding capacities across the field.

The plots were irrigated using four Toro 570™ Series (The Toro Company, Bloomington, MN.) quarter-circle pop-up spray heads with an application rate of 51 mm/h (2 inches/h). The average low quarter distribution uniformity at the site was 0.55, which is considered "fair" by the Irrigation Association (2005).

Experimental design. Rain sensor (RS) treatments were connected to an irrigation time clock to function in bypass mode operation so that a scheduled irrigation event would be bypassed if rainfall depth exceeded the rainfall threshold. A Mini-Clik® (Hunter Industries Inc., San Marcos, CA.) rain sensor was used in seven treatments. The rain sensors were set for two depths of rainfall, 6 mm (0.25 inches) and 3 mm (0.125 inches) and three different frequencies of irrigation events, 1, 2, and 7 d per week. The same total application depth per week was divided over the possible number of days of irrigation per week. An example of the difference in irrigation depth applied per event for different frequencies of irrigation is shown in Table 1. Additionally, there were seven soil moisture sensor (SMS) controlled treatments and two ET controller treatments. All of the ET and SMS treatments were limited to 2 d of irrigation per week. Data from the SMS and ET controlled plots were used for analysis of the effect of water applied on turf quality and rooting depth along with the effect of VWC on wilting presence, treatment effects were not considered in statistical analysis. Analysis of the correlation between frequency and turf quality was performed using only rain sensor and non-irrigated treatments because SMS and ET treatments did not have irrigation schedules with varying frequencies.

There was one control treatment in the experimental design and two time-based comparisons (Table 1). The control was a non-irrigated (NON) treatment. The comparison treatments consisted of a time-based schedule without a rain sensor (WOS), time-based schedule with a rain sensor at 6 mm (WRS, 0.25 inches) and a reduced irrigation schedule with a rain sensor (DWRS) that was scheduled to apply 60% of the possible depth scheduled for WOS and the other RS treatments. Every treatment except for the DWRS and the NON treatments had the same possible total depth of irrigation application. Differences in the amount of irrigation applied were due to bypassed irrigation events (Table 1). Reductions in water applied by DWRS were from both bypassed irrigation events and from a shallower depth applied per irrigation event.

Root sampling. Root samples were collected from all plots on 22 June 2006 and from the plots of nine selected treatments on 25 July 2007. Treatments in 2007 were selected to provide a

Table 1. Summary of irrigation treatment codes and descriptions along with water applied per irrigation event.

Treatment code	Irrigation frequency (days/week)	Water depth applied per irrigation event (mm)[z]	Treatment description
RS1-3mm	1	46	Rain sensor set at 3-mm rainfall threshold[y]
RS2-3mm	2	23	Rain sensor set at 3-mm rainfall threshold
RS7-3mm	7	7	Rain sensor set at 3-mm rainfall threshold
RS1-6mm	1	46	Rain sensor set at 6-mm rainfall threshold
RS2-6mm	2	23	Rain sensor set at 6-mm rainfall threshold
RS7-6mm	7	7	Rain sensor set at 6-mm rainfall threshold
DWRS	2	14	Reduced irrigation schedule 60% of RS2-6mm
WOS	2	23	No rain sensor attached
NON	0	0	No irrigation applied

[z]Depth reported is an example of the irrigation schedule for the month of May
[y]3 mm is equivalent to 0.125 inches, and 6 mm is equivalent to 0.25 inches.

range of irrigation frequencies and total depths of water applied. Samples were taken in a corner of the plots away from edges where turfgrass was well established. The sampling device was constructed out of a 5-cm- (2 inch) diameter metal pipe. Samples were analyzed at two depths: 0 to 15 cm (0 to 6 inches), and 15 to 30 cm (6 to 12 inches). Samples were rinsed over an 18-gauge soil sieve to remove soil from roots, which were placed in an oven at a temperature of 55 °C for 48 h and then weighed. Statistical analyses were performed with Statistical Analysis System software using the General Linear Model, proc GLM (SAS, 2000) comparing the mass of roots at the two sampling depths with total water applied throughout the testing period, average weekly water applied, frequency of irrigation scheduling and year samples were collected. Means separation was conducted with Duncan's multiple range test (SAS Institute, Inc., Cary, NC).

Turf quality. Turfgrass quality was rated at least once every 2 weeks during S06 and F06 and at least once a month during S07 and F07. Quality evaluations were made using the National Turfgrass Evaluation Program (NTEP) procedures (Shearman and Morris, 1998). The ratings were on a 1 to 9 scale, with a 1 representing dead or dormant grass and a 9 representing grass with good color and density, and without weeds (Shearman and Morris, 1998). A quality rating of 5 was considered minimally acceptable for a homeowner lawn.

Statistical analyses for turf quality data were performed with Statistical Analysis System software using the General Linear Model (proc GLM) and the mixed procedure (proc MIXED; SAS, 2000). Comparisons were made between the total amounts of water applied and average weekly water applied (considering irrigation and rainfall), frequency of irrigation, and treatment period. Means separation was conducted with Duncan's multiple range test (SAS Institute, Inc.).

Wilt evaluation. Measurements of the area of wilted turfgrass were taken daily during 2007 over a period from 20 to 29 May 2007 with the exception of 21 May 2007. Measurements were taken in the afternoon when the areas with wilt were easily distinguished. These measurements were then analyzed in comparison to volumetric water content of the soil which was recorded hourly using time domain reflectometry (TDR) sensors (CS616 Water Content Reflectometer, Campbell Scientific, Logan, UT). The TDR sensors were buried in the center of every plot with the top of the sensor at a depth of 8 cm (3 inches) and the bottom of the sensor at a depth of 18 cm (7 inches).

Results

Root sampling. Compared to 2006, root samples in 2007 on average showed increased root mass at both sampling depths. Average root mass, for all plots tested, increased by 37% from 2006 to 2007. In 2007, root mass in the top 15 cm (6 inches) of soil increased by 16% and root mass at the 15 to 30 cm (6 to 12 inches) depth increased by 163%. From 2006 to 2007 the root mass in the top 15 cm (6 inches) increased from 0.96 to 1.11 g and from 0.16 to 0.42 g at the 15 to 30 cm (6 to 12 inches) depth. In 2006, 86% of the total root mass was in the top 15 cm (6 inches) of the soil. In 2007, the percentage of roots in the top 15 cm (6 inches) was 73%. In general, the majority of the root mass was found at the depth of 0 to 15 cm for both years of testing (Figs. 2 and 3).

Total and weekly water applied showed no correlation with root mass ($P = 0.2440$ and $P = 0.1252$; Figs. 2 and 3). The root mass collected for the various irrigation frequencies is shown in Table 2. Root mass at the two sampling depths showed no response to irrigation frequency ($P = 0.2928$).

Water applied and turf quality. In F06 and S07, the non-irrigated treatment was ended early by implementing a timed irrigation schedule to prevent turfgrass death. During both treatment periods, where NON treatments were continued (S06 and F07), it was seen that turf quality ratings for these plots were lower than plots in all other treatments (Table 3). In F07, rainfall was sufficient for maintaining adequate turf quality in NON plots, allowing the treatment to continue throughout the testing period. The plots receiving irrigation 1 d/week had lower turf quality ratings compared to the plots receiving 2 and 7 d/week irrigation (Table 3).

Analyzing total water applied and turfgrass quality data for S06 showed no relationship between the two ($P = 0.4088$), but there was a trend between weekly water applied and turf quality ($P < 0.0001$; Fig. 4A). Between weekly depths applied of 0 and 20 mm (0.8 inches), the trend in turf quality appears to be linearly increasing, but between 20 and 30 mm (0.8 and 1.2 inches) of water applied weekly the relationship becomes less apparent. Poor turf quality for plots receiving more than 30 mm (1.2 inches) of water per week during S06 was most likely due to factors other than the volume of water applied. While all three frequencies of irrigation (1, 2, and 7 d per week) had plots with turf quality ratings of 8 at some point during the testing, the 7 d/week treatment never had a turf quality rating below 4. The 1 d/week treatments had ratings as low as 2. The standard deviation in turf quality for the 7 d/week plots was smaller than the

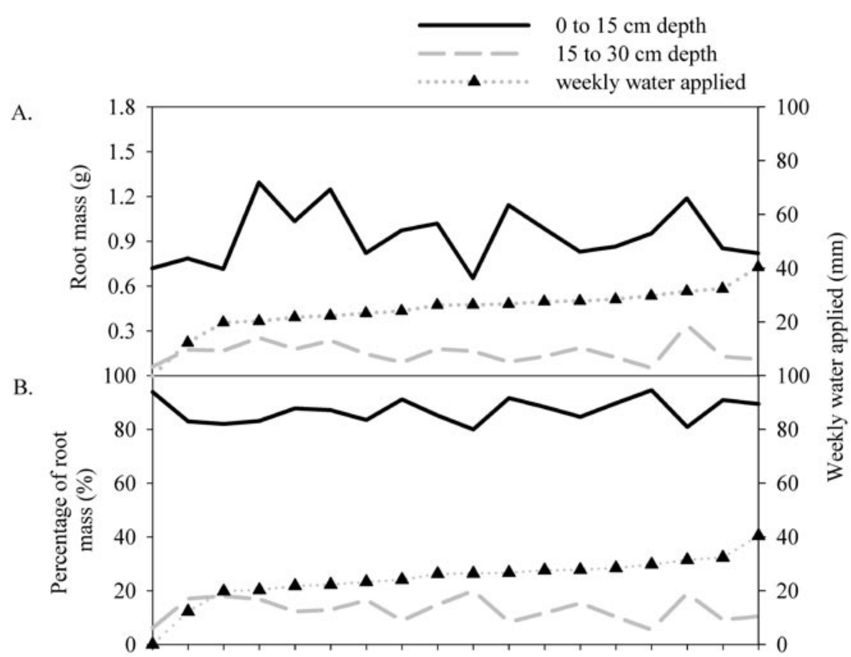

Fig. 2. Graph showing root mass (g) at two depths in the soil profile, 0 to15 cm (0 to 6 inches; circles) and 15 cm to 30 cm (6 to 12 inches; triangles), along with average weekly water applied in 2006.

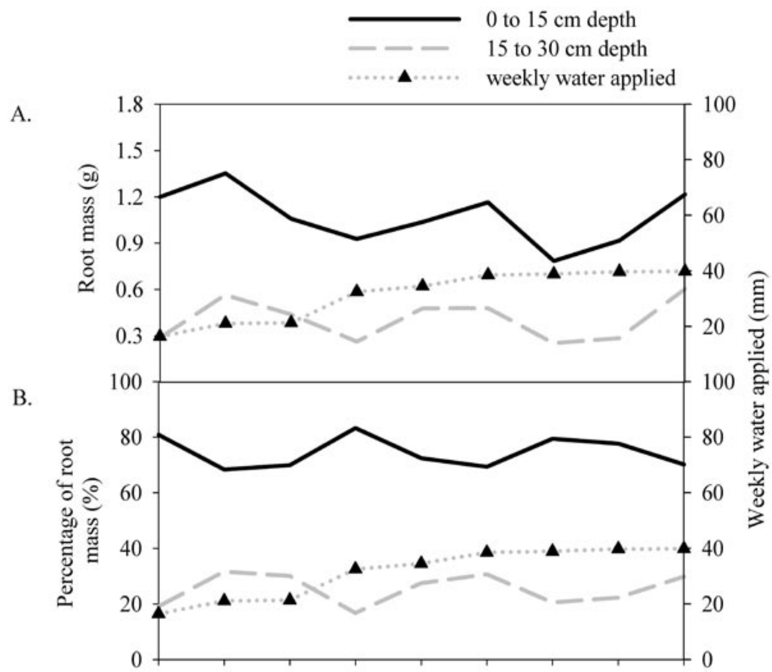

Fig. 3. Graph showing root mass (g) at two depths in the soil profile, 0 to15 cm (0 to 6 inches; circles) and 15 cm to 30 cm (6 to 12 inches; triangles), along with average weekly water applied in 2007.

other irrigation frequencies tested in S06 (Fig. 5A). Both of the 1 d/week treatments had similar low turf quality ratings at the end of S06 ($P = 0.0868$) but only RS1-3mm (rain sensor set at 3 mm, 0.125 inches) was below acceptable (4.3). The other 1 d per week treatment, RS1-6mm, had a rain sensor set at 6 mm (0.25 inches). During S06, the 3 mm (0.125 inches) threshold rain sensor bypassed only one irrigation event more than the 6 mm (0.25 inches) setting resulting in a decrease in turf quality for the RS1-3mm treatment.

No relationship was seen between turf quality and weekly water applied ($P = 0.1501$) during F06 (Fig. 4B) or between turf quality and total water applied ($P = 0.5934$). Frequency of irrigation applied also had no effect on turf quality in F06 ($P = 0.4091$). Turf quality ratings in general were higher in F06 than in S06.

A correlation during the S07 treatment period was seen between both total water applied and turf quality ($P = 0.0139$) and water applied weekly and turf quality ($P < 0.0001$; Figs. 4C and 5C). This treatment period had the strongest relationship between total water applied and turf quality. There was an irrigation frequency effect on turf quality during S07 ($P = 0.0024$). Plots in the 2 and 7 d/week irrigation frequency treatments tended to have higher turf quality than the 1 d/week irrigation plots (Table 3).

In F07, there was a response in turf quality to water applied weekly (Fig. 4D; $P = 0.0268$) but not total water applied (Fig. 4D). This was the only treatment period with rainfall depths greater than historical averages for the area. It received a total of 347 mm (14 inches) of rainfall compared to a historical average of 258 mm (10 inches). The other three treatment periods had rainfall depths that were less than half the historical depth. Turfgrass quality increased with increasing irrigation frequency in F07 (Fig. 5D; $P < 0.0001$). The effect was due to the NON treatment (0 d/week) operating the entire time period. While turf quality ratings in the NON plots were high enough to maintain minimally adequate turf quality, they were lower than the turfgrass quality for plots receiving irrigation 1, 2, or 7 d/week.

Wilt analysis. Analysis of data collected during S07 demonstrated the effect of decreasing volumetric water content on the percentage of wilted turfgrass area. Measurements of the percentage of area displaying signs of wilt along with the volumetric water content (VWC) in the soil at the time of the measurement, separated by block, are shown in Fig. 6. Soil analysis showed

Table 2. Summary of the root mass dried weight (g) collected in 22 June 2006 and 25 July 2007 at two depths, 0 to 15 cm (0 to 6 inches) and from 15 to 30 cm (6 to 12 inches). Irrigation frequency and the year the samples were taken were analyzed for effects on root mass at the two depths of testing.

Irrigation frequency	Root mass from 0 to 15 cm (g)		Root mass from 15 to 30 cm (g)	
(days/week)	2006	2007	2006	2007
0	0.72 *b*	*NA*[z]	0.06 *a*	*NA*
1	1.25 *a*	0.92 *a*	0.24 *a*	0.29 *a*
2	0.93 *ab*	1.17 *a*	0.16 *a*	0.48 *a*
7	0.98 *ab*	0.93 *a*	0.12 *a*	0.26 *a*
CV (%)	34.1	26.7	99.4	68.6
Year comparison	0.96 *b*	1.11 *a*	0.16 *b*	0.42 *a*
CV (%)	31.9		88.8	

Means separation (in columns for comparison of roots based on irrigation frequency and in rows for comparison of years) by Duncan's Multiple Range Test, 5% level.

[z]Indicates sampling analysis was not available for an irrigation frequency of 0 during 2007 because plots for the treatment received supplemental irrigation prior to root sampling.

Table 3. Summary of turf quality analysis showing average turf quality values for each of the four treatment periods S06, F06, S07, and F07. Irrigation frequency and treatment period were both analyzed for effects on average turf quality.

Irrigation frequency	Avg turf quality (1–9 scale)			
(days/week)	S06	F06	S07	F07
0	1.4 *c*	*NA*[z]	*NA*	5.0 *b*
1	4.9 *b*	--[y]	5.8 *c*	6.2 *a*
2	5.9 *a*	6.7 *a*	6.2 *b*	6.4 *a*
7	6.2 *a*	6.5 *a*	6.7 *a*	6.8 *a*
CV	27.7	18.4	18.6	17.1
Treatment period comparison	5.5 *c*	6.7 *a*	6.3 *b*	6.3 *b*
CV		22.4		

Means separation (in columns for comparison of turf quality based on irrigation frequency and in a row for comparison of turf quality between the four testing periods) by Duncan's multiple range test, 5% level.

[z]Non-irrigated treatments were ended early due to poor turf quality. In F06 turf quality was a 2 for plots with an irrigation frequency of 0 by the third week of testing. In S07 this treatment was ended at the end of the first week due to loss of turf quality.

[y]The 1 d/week treatments had a malfunction in the irrigation timer for a period of 20 d causing no irrigation to be applied. Therefore total treatment period averages could not be analyzed for the plots receiving irrigation 1 d/week.

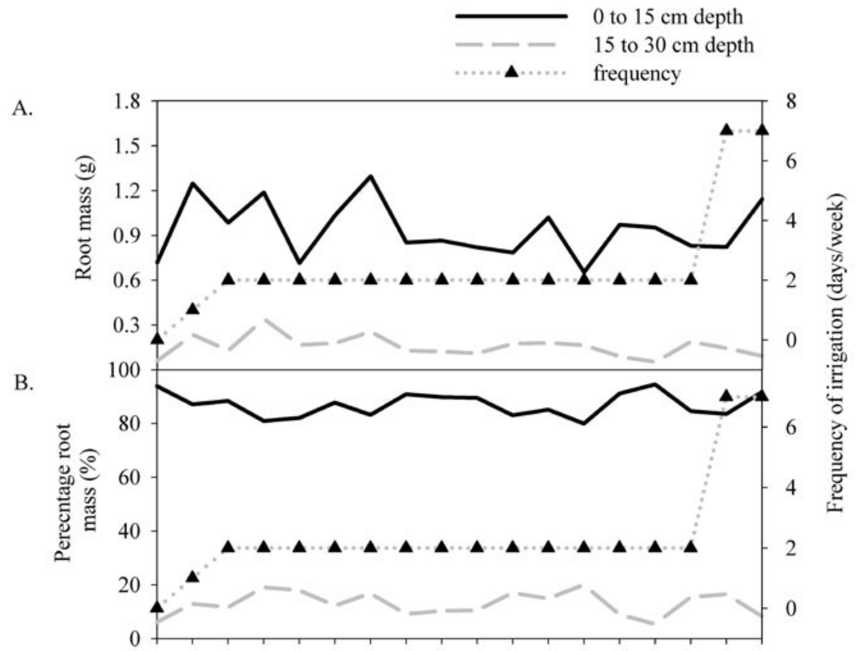

Fig. 4. Average turfgrass quality compared to weekly water applied in (**A**) S06, (**B**) F06, (**C**) S07, and (**D**) F07.

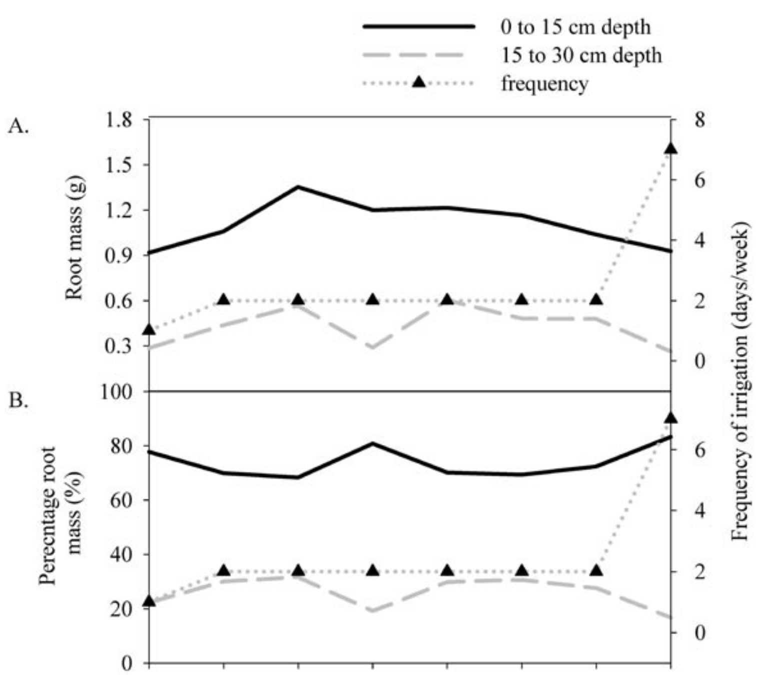

Fig. 5 Box plots comparing frequency of irrigation and turf quality during (**A**) S06, (**B**) F06, (**C**) S07, and (**D**) F07. Black dots represent the average turf quality rating. Error bars represent one standard deviation.

that the soils in these blocks had very different water holding characteristics and so were analyzed separately.

A two piecewise linear equation was used in this analysis to show the trend of wilt with VWC (Fig. 6). The percentage of wilted area tended to increase slowly with decreasing VWC values, but at some value of VWC the area with wilt started to increase much more rapidly. The point at which the wilt began to increase rapidly is the inflection point of the piecewise linear equation. The values of R^2 for these lines varied between 0.38 and 0.67. The lowest correlation (0.38) was in block 1 of the field and the highest (0.67) was in block 2. For blocks 1, 2, and 3 the inflection point occurred at a VWC close to 7%. In block 4 the inflection point was at 11% VWC. The depth of water corresponding to the inflection point where wilt rapidly increased, between 4 and 8 cm (1.5 and 3 inches), was slightly greater than the depth of water corresponding to the average permanent wilting point of the soil.

Conclusions

Rooting depth was not affected by frequency of irrigation or depth of water applied during either year of testing. Total root mass increased between the 2 years of testing by 37%. The largest increase was seen in the 15 to 30 cm (6 to 12 inches) depth, with an increase of 163% from 2006 to 2007. In both 2006 and 2007 large percentages, 86% and 73% respectively, of the total root mass were seen in the top 15 cm (6 inches) of the soil profile. Peacock and Dudeck (1985) also found that varying irrigation intervals (2, 3, 4, or 6 d) did not affect rooting depth on St. Augustinegrass in sandy soil, while rooting depth, in general, increased from one growing season to the next.

During the spring and summer months of testing in both years, frequency of irrigation appeared to have an effect on turf quality, with 2 and 7 d/week irrigation schedules producing better turf quality than 1 day/week. In F07, there was no significant difference in turf quality between the 1, 2, or 7 d/week frequencies of irrigation. Non-irrigated plots produced turf quality significantly lower than the other plots in F07. Sensor setting was an important factor in turf quality for 1 d/week irrigation schedule. The threshold setting needs to ensure adequate water is applied to the turfgrass before bypassing the only irrigation event for the week.

Depth of water applied per week appeared to have a positive correlation with turf quality in S06 and S07, as weekly water applied increased, turf quality increased. Plots receiving less than 20 mm/week (0.8 inches/week) during these treatment periods tended to have decreased turf quality. Testing periods F06 and F07 both had higher average turf quality ratings than S06 and S07, with no correlation between turf quality and water applied. F07 received enough rainfall that non-irrigated plots maintained adequate turf quality throughout the treatment period.

The percent area of wilted turfgrass tended to increase slowly with decreasing soil water content until the soil VWC reached a certain threshold (inflection point). At VWC values below the inflection point wilt increased rapidly. For this experiment three

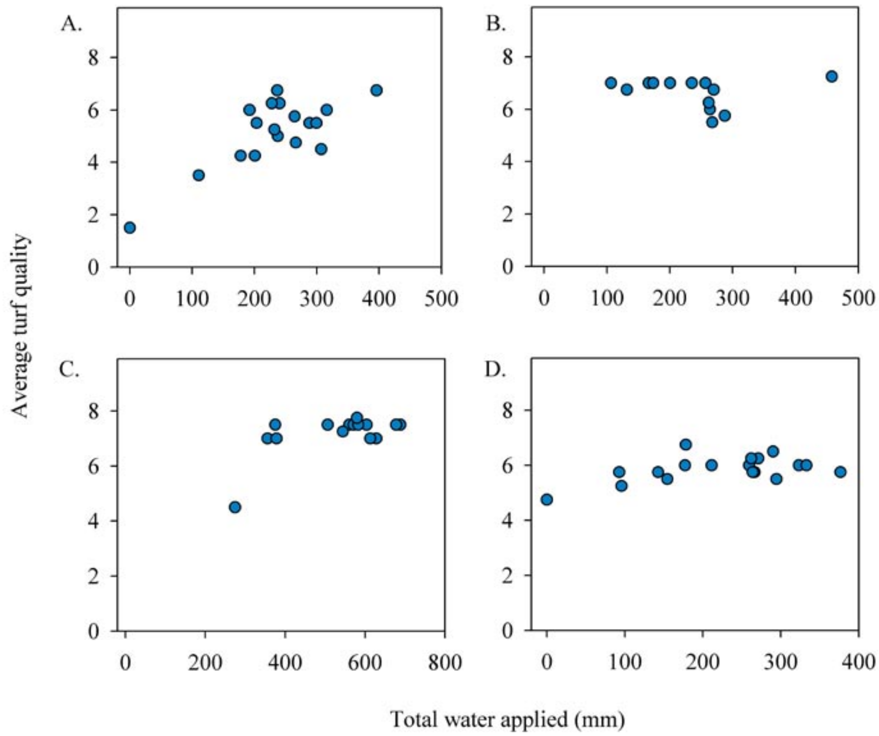

Fig. 6. The effect of volumetric water content (VWC) on the presence of wilting in turfgrass. The scatter plot is the percentage area of turfgrass with the presence of wilt compared to the corresponding volumetric water content. As VWC decreases, before reaching the inflection point in the two piecewise linear equation, wilt increases gradually. After the inflection point the rate of wilting is more rapid with decreasing VWC. Measurements of the area of wilted turfgrass were taken daily from 20 to 29 May 2007 with the exception of 21 May 2007.

out of four blocks in the research site had an inflection point of 7% VWC and the fourth had an inflection point of 10%. These inflection points for three out of four blocks occurred when the depth of water in the soil was between 4 and 8 cm (1.5 and 3 inches) greater than the depth corresponding to permanent wilting point.

Literature Cited

Doss, B.D., D.A. Ashley and O.L. Bennett. 1960. Effect of soil moisture regime on root distribution of warm season forage species. Agron. J. 52:569–572.

Gee, G.W. and J.W Bauder. 1986. Particle-size analysis, p. 383–411. In: A. Klute (ed.). Methods of soil analysis, Part 1 (2nd ed.). Agron. Monogr. 9. Amer. Soc. Agron., Madison, WI, .

Irrigation Association. 2005. Landscape irrigation scheduling and water management. Irr. Assn. Water Mgt. Committee, Falls Church, VA. Available at: <http://www.irrigation.org/gov/pdf/IA_LISWM_MARCH_2005.pdf>. Accessed 17 Jan. 2008.

Kenney, D.S., R.A. Klein, and M.P. Clark. 2004. Use and effectiveness of municipal water restrictions during drought in Colorado. J. Amer. Water Resources Assoc. Paper No. 03072. p. 77–87.

Marella, R.L. 1992. Factors that affect public supply water use in Florida, with a section on projected water use to the year 2020. Water Resources Investigation Rpt. 91-4123. US Dept. of the Interior, U.S. Geological Survey, Tallahassee, FL.

Peacock, C.H. and A.E. Dudeck. 1984. Physiological response of St. Augustinegrass to irrigation scheduling. Agron. J. 76:275–279.

Peacock, C.H. and A.E. Dudeck. 1985. Effect of irrigation interval on St. Augustinegrass rooting. Agron. J. 77:813–815.

SAS (Statistical Analysis System). 2000. SAS/STAT user's guide, Ver. 9. SAS Inst., Cary, NC.

St. Johns River Water Management District (SJRWMD). 2008. Lawn and landscape irrigation rule. Available at: <www.sjrwmd.com>. Accessed 11 Feb. 2008.

Shearman. R.C. and K.N. Morris. 1998. NTEP turfgrass evaluation workbook. NTEP Turfgrass Evaluation Wkshp., 17 Oct. 1998, Beltsville, MD.

Wraith, J.M. and D. Or. 1998. Nonlinear parameter estimation using spreadsheet software. J. Natural Resources and Life Sci. Educ. 27:13-19.