NITROGEN LEACHING, WATER USE RATES AND TURF RESPONSE OF ST. AUGUSTINEGRASS AND BAHIAGRASS TO IRRIGATION AND FERTILIZER PRACTICES

By

PAURIC C. MCGROARY

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2010

This document is dedicated to my family for all their love, help and support.

ACKNOWLEDGMENTS

I would like to thank Drs. John Cisar and George Snyder for their scientific expertise, persistence and support. I am also indebted to my other supervisory committee members, Drs. John Erickson, Jerry Sartain and Samira Daroub, who were always available to answer questions and to provide guidance throughout. I am grateful also to Drs. Alan Wright and Yigang Luo for their help and use of their lab. I would also like to acknowledge the financial support of the Florida Department of Environmental Protection (FDEP). The technical support of Ms. Karen Williams, Ms. Eva King, Mr. Joe Giblin, Mr. Ajambar Rayamajhi, and Mr. Adam Michaud is much appreciated. Finally to my fiancée Holly, for without her love, patience and support I would not have accomplished this dream.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

NITROGEN LEACHING, WATER USE RATES AND TURF RESPONSE OF ST. AUGUSTINEGRASS AND BAHIAGRASS TO IRRIGATION AND FERTILIZER PRACTICES

Pauric C. McGroary

August 2010

Chair: John Cisar
Cochair: George Snyder
Major: Soil and Water Science

In Florida, state regulators are concerned about St. Augustinegrass for both high water use and excess nitrogen (N) applications to home lawns. This has resulted in city ordinances to reduce nitrogen inputs beyond the current statewide regulations under the Urban Turf Fertilizer Rule in order to reduce N leaching. Furthermore, some municipalities have started to replace St. Augustinegrass with bahiagrass in an attempt to conserve water. However, there is limited information available on whether such practices actually help reduce N leaching and conserve water and their effect on St. Augustinegrass quality in subtropical south Florida. Consequently, two experiments were carried out 1) to determine water use rates of St. Augutsinegrass and bahiagrass under two N rates and 2) to evaluate N leaching, water conservation and St. Augustinegrass response to two irrigation regimes and four N rates.

In Experiment 1 under non-limiting water and high N rates, bahiagrass cv. ‘Pensacola’ had comparable or higher water use rates than St Augustinegrass cv. ‘Floratam’. In addition, bahiagrass may require more maintenance due to the faster growth rate in the summer months in south Florida. Additionally, N rate of 98 kg ha^{-1} yr^{-1}

was able to reduced water use rates annually though it did not always produce acceptable quality. In experiment 2, applications of 196, 294 and 588 N/kg ha^{-1} yr^{-1} all produced acceptable quality. However, the applications rate of 588 kg N/kg ha^{-1} yr^{-1} produced greater amount of clippings than 196, 294 kg N/kg ha^{-1} yr^{-1} that may be an inconvenience to some homeowners. Minimum acceptable St. Augustinegrss was produced at 196 kg N/kg ha^{-1} yr^{-1}. Furthermore, both low and high irrigation regimes produced acceptable quality during the experiment. However, water inputs were far greater for the high irrigation regime than the low irrigation regime. Therefore, proving to be ineffective irrigation regime for conserving water compared to the low irrigation regime. Nitrogen rates or irrigation regimes did not influence N leaching. Leaching of NO_3-N never exceeded a mean flow-weighted concentration > 4 mg NO_3-N L^{-1} during the experiment.

CHAPTER 1
EVAPOTRANSPIRATION RATES OF ST AUGUSTINEGRASS AND BAHIAGRASS UNDER VARYING NITROGEN RATES

Introduction

Turfgrass landscapes provide many aesthetic and functional benefits to residents, including opportunities for recreation. However, in order to maintain an acceptable turfgrass landscape, irrigation inputs are required when rainfall is insufficient (Aronson et al., 1987). In fact, the application of water to residential landscapes is a major use of potable water (Baum, 2005). For example, water use in Florida by residential homes accounts for 61% of the public supply category with the average household using 71% of its total water consumption for irrigation use (Baum et al. 2005). As a result, many municipalities across the nation have enacted water restrictions to limit residential irrigation in order to conserve potable water (e.g., South Florida Water Management District). Some municipalities also offer programs for replacing grass with xeriscepes in effort to reduce landscape irrigation (City of Glendale, 2010).

Turfgrass is a major component of urban vegetation and considerable work has been done measuring its water use rates (WURs), which is the total amount of water required for turfgrass growth plus the quantity lost by transpiration and evaporation (evapotranspiration) (ET) from the soil and plant surfaces (Aronson et al., 1987; Beard, 1973; Fu et al., 2004; Fry and Butler, 1989; Kim and Beard, 1988; Park et al., 2005; Youngner et al., 1981). Water loss by grass via ET is influenced by a number of factors, includingclimate, plant morphological and anatomical factors and management practices. Major climatic factors include wind speed (Danielson et al., 1979; Davenport, 1965), solar radiation (Feldhake et al., 1983; Shearman and Beard, 1973) atmospheric vapor pressure, and temperature (Beard, 1973). Management practices include nitrogen (N) fertilization rate (Barton et al., 2009; Ebdon et al., 1999; Feldhake et al., 1983; Mantell, 1966; Shearman and Beard, 1973), fertilizer source (Saha, et al., 2005), mowing height and frequency (Brian et al., 1981; Feldhake et al., 1983; Fry and Butler, 1989; Shearman and Beard, 1973;), use of growth regulators (Borden and Campbell, 1987) and soil water availability (Brian et al., 1981; DaCosta and Huang 2006; Kneebone et al., 1992;) Furthermore WURs varies with turfgrass species (Aronson et al., 1987; Fry and Butler, 1989; Fu et al., 2004; Kim and Beard, 1988; Youngner et al., 1981) and within cultivar of the same species (Bowman and Macaulay, 1991; Ebdon and Petrovic, 1998; Kopec et al., 1988; Shearman, 1986; Salaiz et al., 1991).

St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntz] is one of the most predominately used grass species for residental lawns in the southeastern United States. In Florida alone, St. Augustinegrass is grown on approximately 70% of the lawns with an additional 24,164 ha harvested annually from sod production (Busey, 2003; Haydu et al., 2005). ‘Floratam’ is the most extensively used cultivar due mainly to its resistance to chinch bugs (*Blissus insularis* Barber) but its resistance has been broken (Busey and Center, 1987). Recently, many state regulators in Florida have criticized St. Augustinegrass for its high WURs, as a recent study showed that irrigation for residential landscape accounted for 64% of total residential water use (approx. 141 mm mo^{-1}) for homes surveyed in Central Florida (Haley et al., 2007). This has resulted in a desire by some municipalities to substitute St. Augustinegrass with bahiagrass (*Paspalum notatum* Flügge), which is commonly perceived to use less water (Lower ET) than St. Augustinegrass under irrigated conditions. For example in Orlando, FL the

Orange County commissioners recently had one ha of St. Augustinegrass replaced with bahiagrass in order to reduce water use in the county. However, limited data have indicated comparable ET rates for St. Augustinegrass ‘Floratam’ and bahiagrass ‘Penescola’ in a greenhouse experiment (Miller and McCarty, 2001).

In addition to ET rates, N inputs for St. Augustinegrass lawns have also received great interest due to environmental concerns (Erickson et al., 2001; 2008). Currently, the recommended N rates for South Florida are 196-294 kg ha^{-1} yr^{-1} for St Augustinegrass and 98-196 kg ha^{-1} yr^{-1} for bahiagrass (Trenholm et al., 2000). Few studies have examined the effects of N rates on turfgrass WURs. Although Barton et al. (2009) reported reduced ET at low N rates in Kikuyu turfgrass [*Pennisetum clandestinum* (Hochst. ex Chiov)], the authors suggested that application of the minimum N for turfgrass quality was an approach for decreasing water consumption by turf. However, the implication of these findings for other grass species in other environments is not well understood. Consequently, the aim of this study was to determine the effect of different N fertilizer rates on WURs and turf quality of two warm season grasses commonly used in residential yards in the southeastern U.S.

Materials and Methods

Experimental Site and Design

The study was conducted at the University of Florida’s Institute of Food and Agricultural Sciences, Fort Lauderdale Research and Education Center (26°03’ N, 80°13’ W) on stands of bahiagrass and St. Augustinegrass grown on a mined ‘mason’ sand (Table 1-1) (Atlas Peat and Soil, Inc) that was low (<0.5%) in organic matter and had a pH of 7.9 ± 0.2. The experiment consisting of 16 turfgrass plots in a split-plot randomized complete block design with four replications. Whole plots (8 x 4 m) arranged in blocks consisting of either bahiagrass cv. ‘Pensacola’ or St Augustinegrass cv. ‘Floratam’. One of two N rates (98 and 294 N kg ha^{-1} yr^{-1}) was applied to sub plots (4 x 2 m). Nitrogen rates were split equally over 6 application dates in 2006-2007 (trial 1) and again in 2007-2008 (trial 2). In 2006-2007 N was applied on 12 Oct., 12 Dec. 2006 and 15 Mar., 17 Apr., 18 June, and 16 Aug. 2007. In 2007-2008 N was applied on the 11 Oct., 21 Dec. 2007 and 20 Feb., 21 Apr., 23 June, and 3 Sept. 2008. Each application date represented the start of a new fertilizer cycle (FC). Spray grade granular urea (46-0-0) was used as the source (PCS Sales, Inc. Northbrook, IL) of N and applied with a backpack CO_2-pressurized (30 psi) sprayer equipped with two flat-fan TeeJet 8010 nozzles on 510 mm spacing. Immediately following N applications turfgrass received 13 mm of irrigation to reduce N loss to volatilization and reduce burn potential (Bowman et al., 1987). In addition to N fertilization, P and K from triple superphosphate (0-46-0) and muriate of potash (0-0-63) were applied at the rates of 196 and 392 kg ha^{-1} yr^{-1} to maintain acceptable soil test values. The fertilizers were split equally every 90-days. Additionally, macro and micro-nutrients were applied as Harrell’s Max Minors® containing Mg 1%, S 3.5%, B 0.02%, Cu 0.25%, Fe 4%, Mn 1%, Zn 0.6% and Mo 0.0005% at 12 L ha^{-1} every 90-days. Throughout the duration of the experiment plots received 2.5 mm of irrigation every day except when over 6.4 mm of precipitation occurred. When precipitation events were > 6.4mm then irrigation for the following day was voided. Plots were maintained using a rotary mower at a height of cut of 75 mm and clippings were removed.

Measures of Turfgrass Quality and Clipping Growth

Turfgrass visual quality was assessed biweekly using a 1-9 scale (9 = dark green, 1 = dead/brown turf, and 6.5 = minimally-acceptable turfgrass (Carrow, 1997). Turfgrass clipping samples for shoot growth were harvested from a 2.24 m^2 area within each plot using a rotary mower set at a height of 75 mm approximately weekly or more frequently when necessary. Samples were oven dried at 60^o C for 48 hrs to a constant weight.

Measures of Water Use

In order to measure water use, large lysimeters were installed on top of a 300 mm sand base in the center of each subplot. The lysimeters were constructed from plastic drums 920 mm high, 597 mm diameter, with a 13 mm thick wall, (US Plastics Corporation) with a flat bottom which had a threaded opening already manufactured into the container for easy drainage pipe installations. The lysimeters were fitted with 19 mm polyvinyl chloride (PVC) drainage pipe, spliced to allow for lysimeter drainage and individually installed on the foundation. A 90-degree elbow joint was attached to drainage orifice, which was subsequently connected to a 10 mm section of 24 mm diameter Schedule 40 PVC pipe that ran to a collection station. At the collection station each pipe was allocated its own 20 L polyethylene container. Each lysimeter had a stainless steel screen (1 mm mesh) over the orfice at the bottom of the lysimeter. This subsequently was covered with a 100 mm layer of filter gravel (>14 mm 1%, 12-14 mm 7.5%, 9-12 mm 10.5%, 6.73-9 mm 28%, 6-6.73 mm 41%, 4-6 mm 7%, 2-4 mm 3.5%, <2mm 1.5%) which was overlaid by 5 cm layer of choker sand (>2 mm 0.1%, 1-2 mm, 7.6%, 0.5-1.0 mm 26%, 0.25-0.5 mm 45.6%, 0.15-0.25 mm 19.1%, 0.053-0.15 1.2%, <0.053 0.6%). Similar a layer was installed outside the lysimeter so the soil profiles were similar. Subsequently, mason sand was packed around, between and within each of the lysimeters to a depth of 780 mm. Furthermore, a 75 mm layer of mason sand was spread uniformly over the top of the lysimeters. Perimeter irrigation systems were installed on each of the main plots. The irrigation system comprised of 24 mm diameter Schedule 40 PVC pipe with rotor Rainbird 3500 sprinklers placed in each corner adjusted to spray an inward quarter circle.

Water use rates were determined by using the following calculation WURs = (rainfall + irrigation)-(percolate + runoff) (Park et al., 2005). Runoff was omitted from the equation, as it was never observed. Rainfall data was obtained from a Florida Automated Weather Network (FAWN) station which was located within 500 m of the test site Percolate and volumes were measured weekly and more frequently following precipitation events exceeding 25 mm.

St. Augustinegrass and bahiagrass were sodded in their designated plots. Additionally, berm areas were also sodded with St. Augustinegrass. Within the first week after sod installation, a blended granular fertilizer (26-3-11) was applied to all the plots at a rate of 50 kg N ha^{-1} yr^{--1}.This was followed a month later with an application of 6-6-6 at a rate of 50 kg N ha^{-1} yr^{-1}. Before the actual initiation of the trials, grass was allowed to establish for a period of 6 months. Throughout the first three months of the establishment period irrigation was applied three times a week at 13 mm per application. However, for the final three months of establishment, irrigation was adjusted to 2.5 mm per day.

Analysis of Data

All data were analyzed for normality using the Shapiro-Wilk W test. Homogeneity of variance was also checked graphically. Clipping yields (CYs) and WURs were totaled for each fertilizer cycle and year. Quality ratings were averaged over each FC and trial. Analyses were performed on individual fertilizer cycle–trial data because the length of the fertilizer cycles varied from trial to trial. All data were subjected to analysis of variance with PROC GLM (SAS Institute, 1999) and means were separated using Fisher's Least Significant Difference (LSD) at the t-probability level of 0.05.

Results

Climate

Average daily temperatures ranged from 22-28°C for trial 1 (14 October 2006 to 04 October 2007) and 21-28°C for trial 2 (05 October 2007 to 05 November 2008) (Table 1-2). However, in both trials air temperatures were generally lower in FC1, FC2, and FC3 compared to FC4, FC5 and FC6. Rainfall varied slightly between trials. During trials 1 and 2 plots received a total of 1658 mm and 1538 mm of rainfall (Table 2). Furthermore, rainfall in both trials was generally greater during FC4, FC5, and FC6 compared to FC1, FC2 and FC3.

Turfgrass Growth and Quality

Clipping yields were affected by grass ($P < 0.01$) and N rate ($P < 0.01$) in both trials (Table 1-3, 1-4). Clipping yields from each FC (Trial 1, FC3) were greater for bahiagrass than St. Augustinegrass (Table 1-3; 1-4). Total clipping yields for each trial were approximately 4 times greater from bahiagrass compared to St. Augustinegrass, averaging 6988 and 1510 kg ha^{-1} for trial 1 and 4457 and 1369 kg ha^{-1} for trial 2, respectively. In general both grasses produced the greatest CYs during FC4, F C5, and FC6 (Table 1-3, 1-4). Additionally, the higher N rate (averaged across grasses) significantly increased CYs by about 60% for each trial. In both trials, for each cycle except FC1 and FC3 in trial 1 increasing the N rate from 98 to 294 kg ha^{-1} yr^{-1} significantly increased clipping yields.

Both grass species and N rates produced acceptable quality (> 6.5) when averaged across each trial. Bahiagrass quality scores were equal to or higher than St. Augustinegrass across both trials but were only significantly different in (P < 0.05) in three out of the 12 cycles (Table 1-5, 1-6). Although, the higher N rate always produced higher quality scores than the lower N rate. It was only significantly higher in FC1, FC2, FC3, and FC5 in trial 1 (Table 1-5) and FC3, FC6 in trial 2 (Table 1-6). Although the lower N rate produced acceptable quality when averaged across trials, there were times when quality was not acceptable, such as FC3 in trial 1 and FC2, FC3 and FC6 in trial 2.

Turfgrass Water Use Rate

Total water use rate (TWURs) was greater (P < 0.05) from bahiagrass compared to St. Augustinegrass during trial 1, averaging 1508 and 1286 mm, respectively (Table 1-7). However, no significant difference was seen between the grasses during trial 2 (Table 1-8). In trial 1, bahiagrass showed significantly greater WURs in three out of the six cycles, but bahiagrass WURs were only significantly greater in one cycle out of the six cycles in trial 2 (Table 1-7, 1-8). In general, both grasses had higher WURs during FC4, FC5, and FC6 of both trials. The high N rate (P < 0.05) increased TWURs by about 8% in trial 1, no significant difference was found in trial 2 (Table 1-7, 1-8).

Discussion

With increasing concern over scarcity of water resources, pressure has been placed on residents to reduce water use, especially when it comes to irrigation of landscape areas such as yards and flower beds. While St. Augustinegrass is the most widely used grass for home yards in Florida, it has been suggested that bahiagrass should be used instead for its lower water use. In this study the quality, growth and WURs of two grasses were compared under well-watered conditions utilizing two N rates commonly applied by the lawn care industry. Results indicate that St. Augustinegrass WURs was comparable or less than bahiagrass maintained in field conditions.

In the current study the TWURs for St. Augustinegrass were 1,286 mm during trial 1 and 1,200 mm during trial 2, which were similar to that reported by Steward and Mills (1967) of 1,067 mm for St. Augustinegrass. Total water use rates for both grasses was higher during trial 1 than trial 2. A similar trend was observed in CYs, whereby yields were greater in trial 1 than trial 2. Increased evaporative demand coupled with reduced water inputs during trial 2 (Table 1-2) likely contributed to the lower CYs seen during trial 2, which may explain why TWURs was lower in trial 2 compared to trial 1.

Throughout both trials WURs were generally comparable between both grasses, and in some cases WURs were even greater for bahiagrass compared to St. Augustinegrass (Table 1-7, 1-8). This may be explained by the fact that bahiagrass produced significantly greater CYs than St. Augustinegrass, thus requiring more water to support the increased growth (Barton et al., 2009; Brian et al., 1981). For example, Barton et al. (2009) found that growth accounted for 75% of the variation in ET in kikuyu turfgrass. Furthermore, differences in WURs between bahiagrass and St Augustinegrass may also be explained by leaf orientation and shoot density difference between the two grasses: St. Augustinegrass has a higher shoot density and a substantial horizontal leaf orientation compared to bahiagrass which has a more vertical leaf orientation and low shoot density (Kim and Beard, 1988). This vertical leaf orientation and lower shoot density of bahiagrass leads to lower canopy resistance and thus higher ET rates compared to a grass that has a higher canopy resistance (Kim and Beard, 1988; Brian et al., 1981). Water use rates rates were generally higher in FC4, FC5, and FC6 of each trial. This may be attributed to the greater canopy leaf area and higher evaporative demand due to higher temperatures and longer photoperiod. Throughout the duration of the experiment wilting was never observed in any of the plots. Thus, each grass was evaluated under non deficit conditions. However, it should be noted that even though bahiagrass used more water than St. Augustinegrass at times in our study, bahiagrass may require less frequent and total irrigation, since bahiagrass has a greater capacity to avoid water stress compared to St. Augustinegrass (Miller and McCarty, 2001) and subsequently, requiring less frequent irrigation. In addition, bahiagrass has the ability to survive periods when water is not available through its capacity for dehydration avoidance (McCarty and Cisar, 1995) which allows the grass to green up after watering. St. Augustinegrass does not encompass such a mechanism. Therefore, when water becomes limiting the grass normally enters drought and can potentially dies. Even though bahiagrass used more water under well watered conditions in our study, it may be able to survive water deficit conditions better than St. Augustinegrass, and thus allowing it to survive under lower and more infrequent water inputs.

Water use rates were also affected by N fertilization rates; however these differences were relatively modest, especially in comparison to the difference between species. Furthermore, reducing N fertilizer rates by 67% resulted in a 5-8 % reduction in WURs per trial. Similar results were reported for Kikulyugrass when decreasing N rates reduced ET (Barton, et al., 2009). The reduction in WURs at low N was likely due to the lower water use associated with reduced leaf area and clipping yield production seen at low N (Brian et al., 1981; Barton et al., 2009). In the future if water restrictions are heightened for home yards, manipulating of N rates may be a possible management strategy in reducing water use rates of grasses and ultimately conserving water. Throughout the duration of the experiment both grasses produced acceptable turfgrass quality scores demonstrating that both grasses can be used to produce aesthetically pleasing home yards with reduced inputs of irrigation and N . However, clipping yields showed that St. Augustinegrass (approx. 260%) responded much more to fertilization than bahiagrass (approx. 35%), which was remarkably consistent across both trials. Nevertheless, increasing N rates from 98 to 294 kg ha^{-1} yr^{-1} improved quality in trial 1 and 2 for both grasses. Finally, clipping production varied greatly between grass species. Bahiagrass growth rate was generally higher than St. Augustinegrass which increased the frequency of mowing especially during FC4, FC5, and FC6 of each trial. This may not be favored by homeowners as it may increase fuel, labor costs and waste disposal of clippings (Fluck and Busey, 1988). Further work is needed to evaluate bahiagrass response to lower N rates and irrigation as it may be possible to reduce N rate without compromising turf quality. This may help in reducing WURs rates due to the reduction in growth and the risk of N leaching.

Conclusion

While the results from this experiment varied across trials, some general conclusions can be made regarding grasses and N management impacts on WURs rates. First, under non-limiting water and high N rates, bahiagrass cv. ‘Pensacola’ had comparable or higher WURs rates than St Augustinegrass cv. ‘Floratam’. Second, both St. Augustinegrass and bahiagrass can be used to produce acceptable quality lawns. However, bahiagrass may require more maintenance due to the faster growth rate especially during the warmer wetter summer months in south Florida. Finally, N rate of 98 kg ha^{-1} yr^{-1} was able to reduce WURs annually though it did not always produce acceptable quality.

Table 1-1. Percentage by weight of mineral particle fractions contained in the rootzone used for construction of the field study area.

Name	Size range	Weight
	--------mm------	----%----
Fine Gravel	2.0 - 3.4	0
Very coarse sand	1.0 - 2.0	2
Coarse sand	0.5 - 1.0	7
Medium sand	0.25 - 0.50	23
Fine sand	0.15 - 0.25	27
Very Fine Sand	0.05 - 0.15	34
Silt	0.002 - 0.05	7
Clay	less than 0.002	0

Table 1-2. Total rainfall, total irrigation, total evapotranspiration and average daily air temperature for each cycle of the trials at Ft Lauderdale, FL.

Study[a] period	Cycle	No. days	Rainfall	Irrigation	Reference ET†	Min. air temp.	Max. air temp.	Ave. air temp.
			--------------------mm------------------			--------------°C-------------		
Trial 1	1	61	173	145	133	6	31	23
	2	88	120	213	194	8	30	22
	3	27	57	69	97	12	29	22
	4	64	348	127	247	12	34	25
	5	61	525	162	273	15	35	27
	6	49	435	91	194	22	35	28
	Total	350	1658	807	1138	-	-	-
Trial 2	1	76	210	178	179	10	32	24
	2	56	142	135	113	3	30	21
	3	65	157	137	220	8	32	23
	4	62	158	145	291	17	35	26
	5	58	439	112	257	21	35	28
	6	75	432	170	244	22	32	26
	Total	392	1538	877	1304	-	-	-

[a]Trial 1 Cycle 1, 14 October 2006 to 14 December 2006; Cycle 2, 15 December 2006 to 13 March 2007; Cycle 3, 14 March 2007 to 10 April 2007; Cycle 4, 11 April 2007 to 14 June 2007; Cycle 5, 15 June 2007 to 15 August 2007; Cycle 6, 16 August 2007 to 4 October 2007.

Trial 2 Cycle 1, 5 October 2007 to 20 December 2007; Cycle 2, 21 December 2007 to 15 February 2008; Cycle 3, 16 February 2008 to 21 April 2008; Cycle 4, 22 April 2008 to 23 June 2008; Cycle 5, 24 June 2008 to 21 August 2008; Cycle 6, 22 August 2008 to 5 November 2008.

† Reference Evapotranspiration (ET) was calculated using a modified Penman equation.

Table 1-3. Trial 1 treatment means for dry weight of clippings of bahaiagrass and St. Augustinegrass at two N application rates.

Factor		2006-2007 C1	C2	C3	C4	C5	C6	Total
		---kg ha $^{-1}$---						
Grass (G)								
Bahiagrass		250	205	335	1316	2463	2373	6988
St. Augustinegrass		44	89	89	233	564	492	1510
Sig.		**	NS	*	*	**	**	**
LSD 0.05		81	-	194	1005	846	586	2328
Nitrogen (N) (kg ha^{-1} yr^{-1})								
98		134	99	189	567	1211	1107	3307
294		204	195	234	982	1817	1759	5191
Sig.		NS	*	NS	*	*	*	*
LSD 0.05		-	66	-	398	544	447	1490
G X N Interaction								
Bahiagrass	98	236	161	311	1051	2200	2020	5978
Bahiagrass	294	354	250	359	1581	2726	2727	7998
St. Augustinegrass	98	33	18	68	83	222	193	636
St. Augustinegrass	294	55	29	109	383	906	790	2384
Sig.		NS	NS	NS	NS	NS	NS	NS

NS, *, **, and *** = P > 0.05, P < 0.05, P < 0.01, P < 0.001

Table 1-4. Trial 2 treatment means for dry weight of clippings of bahaiagrass and St. Augustinegrass at two N application rates.

Factor		2007-2008 C1	C2	C3	C4	C5	C6	Total
		---kg ha $^{-1}$---						
Grass (G)								
Bahiagrass		393	ND	145	659	2066	1193	4457
St. Augustinegrass		105	ND	171	128	367	598	1369
Sig.		**		NS	*	**	**	**
LSD 0.05		146		-	349	780	302	1552
Nitrogen (N) (kg ha^{-1} yr^{-1})								
98		186	ND	65	257	985	700	2193
294		312	ND	251	529	1449	1091	3633
Sig.		*		*	**	*	*	*
LSD 0.05		74		128	141	377	322	1000
G X N Interaction								
Bahiagrass	98	399	ND	102	490	1812	1039	3783
Bahiagrass	294	446	ND	188	827	2321	1346	5130
St. Augustinegrass	98	32	ND	29	24	157	360	601
St. Augustinegrass	294	178	ND	314	232	577	836	2137
Sig.		NS		NS	NS	NS	NS	NS

NS, *, **, and *** = P > 0.05, P < 0.05, P < 0.01, P < 0.001
ND, No data was collected during this cycle

Table 1-5. Trial 1 treatment means for turfgrass quality of bahiagrass and St. Augustinegrass at two N application rates.

Factor		2006-2007						
		C1	C2	C3	C4	C5	C6	Average
		--------------------------------1-9--------------------------------						
Grass (G)								
Bahiagrass		7.2	6.9	7.0	7.5	7.1	7.0	7.2
St. Augustinegrass		6.6	6.6	6.6	6.7	6.8	6.8	6.7
Sig.		***	NS	NS	NS	NS	NS	NS
LSD 0.05		0.3	0.6	0.5	0.7	0.3	0.7	0.4
Nitrogen (N) (kg ha^{-1} yr^{-1})								
98		6.7	6.5	6.4	6.8	6.7	6.8	6.7
294		7.2	7.1	7.1	7.4	7.2	7.1	7.2
Sig.		**	*	*	NS	*	NS	*
LSD 0.05		0.3	0.6	0.5	-	0.3	-	0.4
G X N Interaction								
Bahiagrass	98	7.0	6.8	6.6	7.3	7.0	7.0	7.0
Bahiagrass	294	7.4	7.2	7.3	7.7	7.2	7.2	7.4
St. Augustinegrass	98	6.3	6.2	6.3	6.3	6.4	6.7	6.4
St. Augustinegrass	294	7.0	7.1	6.8	7.1	7.2	7.0	7.1
Sig.		NS	NS	NS	NS	NS	NS	NS

NS, *, **, and *** = P > 0.05, P < 0.05, P < 0.01, P < 0.001

Table 1-6. Trial 2 treatment means for turfgrass quality of bahiagrass and St. Augustinegrass at two N application rates.

Factor		2007-2008						
		C1	C2	C3	C4	C5	C6	Average
		--------------------------------1-9--------------------------------						
Grass (G)								
Bahiagrass		7.1	7.0	7.0	7.3	7.3	7.0	7.1
St. Augustinegrass		6.6	6.4	6.3	6.5	6.5	6.4	6.5
Sig.		NS	NS	*	*	NS	NS	NS
LSD 0.05		-	-	0.5	0.7	-	-	-
Nitrogen (N) (kg ha^{-1} yr^{-1})								
98		6.6	6.4	6.3	6.7	6.7	6.3	6.5
294		7.0	7.0	7.0	7.1	7.1	7.1	7.1
Sig.		NS	NS	*	NS	NS	*	NS
LSD 0.05		-	-	0.5	-	-	0.4	-
G X N Interaction								
Bahiagrass	98	7.0	6.8	6.8	7.1	7.0	6.7	6.9
Bahiagrass	294	7.3	7.3	7.4	7.5	7.5	7.4	7.4
St. Augustinegrass	98	6.3	5.9	5.7	6.3	6.4	5.9	6.1
St. Augustinegrass	294	6.9	6.7	6.6	6.7	6.6	6.8	6.7
Sig.		NS	NS	NS	NS	NS	NS	NS

NS, and *, = P > 0.05, P < 0.05

Table 1-7. Trial 1 treatment means for water use rates of bahaiagrass and St. Augustinegrass at two N application rates.

Factor		2006-2007						
		C1	C2	C3	C4	C5	C6	Total
		---------			mm			---------
Grass (G)								
Bahiagrass		177	189	114	309	345	374	1508
St. Augustinegrass		122	159	88	238	321	360	1288
Sig.		*	NS	*	**	NS	NS	*
LSD 0.05		15	-	116	65	-	-	80
Nitrogen (N) (kg ha^{-1} yr^{-1})								
98		136	160	95	270	319	361	1341
294		162	188	106	277	347	372	1452
Sig.		**	*	*	NS	*	*	*
LSD 0.05		15	20	11	-	27	10	80
G X N Interaction								
Bahiagrass	98	170	192	113	326	342	373	1516
Bahiagrass	294	183	187	114	293	349	375	1501
St. Augustinegrass	98	102	128	78	214	297	349	1168
St. Augustinegrass	294	142	190	98	261	346	370	1407
Sig.		NS	NS	NS	NS	NS	NS	NS

NS, *, and **, = P > 0.05, P < 0.05, P < 0.01

Table 1-8. Trial 2 treatment means for water use rates of bahiagrass and St. Augustinegrass at two N application rates.

Factor		2007-2008						
		C1	C2	C3	C4	C5	C6	Total
		---------			mm			---------
Grass (G)								
Bahiagrass		184	139	220	276	294	185	1298
St. Augustinegrass		159	126	205	264	265	181	1200
Sig.		*	-	-	-	-	-	-
LSD 0.05		14	21	38	29	55	51	175
Nitrogen (N) (kg ha^{-1} yr^{-1})								
98		165	134	208	261	267	179	1214
294		179	131	217	279	290	187	1283
Sig.		*	NS	NS	NS	NS	NS	NS
LSD 0.05		14	-	-	-	-	-	-
G X N Interaction								
Bahiagrass	98	184	143	221	272	291	182	1293
Bahiagrass	294	185	135	219	280	297	188	1304
St. Augustinegrass	98	146	125	196	250	247	175	1139
St. Augustinegrass	294	173	127	215	278	283	186	1262
Sig.		NS	NS	NS	NS	NS	NS	NS

NS, and *, = P > 0.05, P < 0.05

CHAPTER 2
EFFECTS OF IRRIGATION REGIMES AND NITROGEN RATES ON NITROGEN LEACHING FROM ST. AUGUSTINEGRASS YARDS

Introduction

Nitrogen is essential for growth and function and is the mineral nutrient required in the greatest quantity by turfgrasses (Beard, 1973). When N is maintained at sufficient levels, N can promote vigor, visual quality, recovery from damage and overall health (Bowman et al., 2002). Consequently, N fertilizers are frequently used to maintain or improve density and the aesthetics of residential landscapes as the amount of N in most soils is insufficient to support acceptable aesthetics of residential yards (Cisar et al., 1991). When N is applied to turfgrass, it can exit the turf/soil system via gaseous losses such as volatilization and denitrification, groundwater leaching, runoff, and clipping removal (Petrovic, 1990). Of these processes, the regulatory and environmental groups perceive nitrate (NO_3-N) leaching as the greatest environmental threat due to its mobility and its inability to be retained on soil colloids (Bowman et al., 2002). Nitrate is considered one of the most widespread contaminants among the world's aquifers and can lead to eutrophication and algal blooms in near shore environments and lakes (Spalding and Exner, 1993). It is also considered a human health threat if NO_3-N levels exceed 10 mg L^{-1} in drinking water as it can cause the syndrome known as methemoglobinemia also called "blue baby syndrome" (USEPA, 1976). In Florida, NO_3-N leaching from home lawns has been implicated as a potential source of N pollution to streams, lakes, springs and bays (Erickson et al., 2001; Flipse et al., 1984). With expanding residential land use and increasing urban population in Florida, greater quantities of fertilizer may be applied, which could contribute to problems associated with NO_3-N contamination in water. In addition, residential soils in southern Florida are generally coarse-textured with little ability to retain either N or water which may further increase leaching of NO_3-N especially after excess precipitation (Cisar et al., 1991; Erickson et al., 2008).

To date, research-examining fertilizer N leaching from turfgrass generally has shown low potential of N leaching from turfgrass (Erickson et al., 2008; Reike and Ellis, 1974; Sheard et al., 1985; Starr and DeRoo, 1981; Mancino and Troll, 1990; Miltner et al., 1996). However, higher N leaching losses have shown to be greatly influenced by several management factors including N rate, N source, N frequency, N application methods, irrigation management, turfgrass establishment, and species or cultivar selection (Barton, et al., 2006; Bowman et al., 2002; Cisar et al., 1991; Erickson et al., 2010; Geron et al., 1993; Reike and Ellis, 1974; Snyder et al., 1984; Snyder et al., 1989; Petrovic, 1990). For example, soluble N fertilizer sources used at the same rates and frequencies of slow release or organic sources tend to increase leaching (Eason and Petrovic, 2004). Furthermore, increasing irrigation and precipitation in excess of ET has shown to increase N leaching (Barton et al., 2006; Morton et al., 1988; Snyder et al., 1984). For example, Snyder et al., (1984) demonstrated on bermudagrass that scheduling irrigation on soil moisture depletion could reduce NO_3-N to <1% compared to daily irrigation that resulted in losses ranging from 22 to 56%.

In 2002, Best Management Practices in Florida were developed by regulatory, academic and industry professionals after research had shown that fertilizer management was a major factor in reducing non-point source pollution (Gross et al., 1990; Trenholm et al., 2002). Currently, published research for St. Augustinegrass has examined the effects of sod type, irrigation, and fertilization on newly established St.

Augustinegarss sod, contrasting landscapes (mixed species vs. St. Augustinegrass) and rates of quick release vs. slow release N fertilizer on ornamentals and St. Augustinegrass NO_3-N leaching (Erickson et al, 2001; Erickson et al., 2008; Erickson et al., 2010; Saha, et al., 2005). However, there are no published data on the impact of other management practices such as irrigation, soluble N rates and the combination of these factors on N leaching from mature St. Augustinegrass yards.

Current state-wide regulations in Florida under the Urban Turf Fertilizer Rule has limited N applications to 49 kg N ha^{-1} per application of which, the water-soluble N portion should not exceed 34 kg N ha^{-1} (Department of Agricultural and Consumer Services (DACS), No. 4640400, Rule 5E-1.003, 2007). Furthermore, some local ordinances impose stricter N fertilizer guidelines than the ones under the Urban Turf Fertilizer Rule in an attempt to further reduce N leaching. For example, the City of Sanibel enacted Ordinance No. 07-003 (Council of the City of Sanibel, Water Resources Department), which prohibits N fertilization during the traditional rainy season in South Florida from June 1 through September 30, restricts annual N applied as fertilizer to 196 kg ha^{-1}, and further limits the per-application soluble N portion of fertilizer to 24.5 kg ha^{-1}. However, no research has reported that such fertilizer practices actually needed to reduce N leaching from St Augustinegrass. In addition, water restrictions on home yards restrict irrigation of home yards to at least three days per week (Phase 1) to once a week (Phase 3) or none (South Florida Water Management District, 2010) (SFWMD) depending on the ordinance and water restriction in place to conserve water. Given that there is little data supporting the claims that these management practices or similar ones can reduce N leaching from St.

Augustinegrass yards in south Florida, we conducted a study to determine how irrigation regimes and N rates influence inorganic-N leaching from established St. Augustinegrass.

Materials and Methods

Experimental Site and Design

The study was conducted at the University of Florida's Institute of Food and Agricultural Sciences (IFAS), Fort Lauderdale Research and Education Center (26°03' N, 80°13' W) on an stand of St. Augustinegrass (cv. 'Floratam'), which was initially produced on sand soil and then grown on a mined landscape-type sand (Atlas Peat and Soil, Inc) that was low (<0.5%) in organic matter (Table 2-1) with a pH of 7.9 ± 0.2. Sand was used as the rootzone media for this experiment as to demonstrate a worst case scenario situation (Table 2-1). The experiment consisted of 32 plots in a split-plot randomized complete block design with four replications repeated over two trials. Main blocks (8 x 4 m) consisted of one of two irrigation regimes: 2.5 mm daily (Low) except when daily precipitation > 6.4 mm (irrigation turned off), and 13.0 mm three times weekly (High) simulating a Phase 1 water use restriction that is used by the South Florida Water Management District under water shortages (SFWMD, 2010). Subplots (2 x 4 m) consisted of four N rates (98, 196, 294 and 588 kg N ha^{-1} yr^{-1}). The 588kg N ha^{-1} yr^{-1}, which is double the recommend rate for this geographical region by IFAS (Trenholm et al., 2000), was included in the study as a worst-case scenario for excessive N applications to home yards in south Florida. The 294 kg N ha^{-1} yr^{-1}rate is suggested for south Florida conditions with appreciable soil organic matter, 196 kg N ha^{-1} yr^{-1} is more comparable to central/north Florida with a shorter growing season and the 98 kg rate is recommended for the University of Florida "Florida Yards and

Neighborhood" resource efficient landscapes that include turf. Nitrogen rates were split over 6 application dates. In 2006-2007 N was applied on the 12 Oct., 12 Dec. 2006 and 15 Mar., 17 Apr., 18 June, and 16 Aug. 2007. In 2007-2008, N was applied on the 11 Oct., 21 Dec. 2007 and 20 Feb., 21 Apr., 23 June, and 3 Sept. 2008. Each application date represented the start of a new fertilizer cycle (FC). Spray grade granular urea (46-0-0) was used as the source of N and was applied with a backpack CO_2-pressurized (30 psi) sprayer equipped with two flat-fan TeeJet 8010 nozzles on 510 mm spacing as per industry standard method of application. Immediately following N applications, plots received 13 mm of irrigation to reduce loss by volatilization and reduce burn potential (Bowman et al., 1987). In addition to N fertilization, P and K from triple superphosphate (0-46-0) and muriate of potash (0-0-60) were applied to maintain acceptable soil test values at the rate of 196 and 392 kg ha^{-1} yr^{-1}, split equally every 90-d, respectively. Additionally, micro-nutrients were applied as Harrell's Max Minors® containing Mg 1%, S 3.5%, B 0.02%, Cu 0.25%, Fe 4%, Mn 1%, Zn 0.6% and Mo 0.0005% at 12 L ha^{-1} every 90-days. Plot were maintained using a rotary mower at a height of cut of 75 mm and clippings were removed.

Measure of Percolate and Nutrient Leaching

Drainage was measured using lysimeters inserted into each of the plots on top of a 300 mm sand base in the center of each subplot. The lysimeters were constructed from plastic drums 920 mm high, 597 mm diameter, with a 13 mm thick wall, (US Plastics Corporation) with a flat bottom which had a threaded opening already manufactured into the container for easy drainage pipe installations. The lysimeters were fitted with 19 mm polyvinyl chloride (PVC) drainage pipe, spliced to allow for lysimeter drainage and individually installed on the foundation. A 90-degree elbow joint was attached to drainage orifice, which was subsequently connected to a 10 mm section of 24 mm diameter Schedule 40 PVC pipe that ran to a collection station. At the collection station each pipe was allocated its own 20 L polyethylene container. Each lysimeter had a stainless steel screen (1 mm mesh) over the orfice at the bottom of the lysimeter. This subsequently was covered with a 100 mm layer of filter gravel (>14 mm 1%, 12-14 mm 7.5%, 9-12 mm 10.5%, 6.73-9 mm 28%, 6-6.73 mm 41%, 4-6 mm 7%, 2-4 mm 3.5%, <2mm 1.5%) which was overlaid by 5 cm layer of choker sand (>2 mm 0.1%, 1-2 mm, 7.6%, 0.5-1.0 mm 26%, 0.25-0.5 mm 45.6%, 0.15-0.25 mm 19.1%, 0.053-0.15 1.2%, <0.053 0.6%). Similar a layer was installed outside the lysimeter so the soil profiles were similar. Subsequently, mason sand was packed around, between and within each of the lysimeters to a depth of 780 mm. Furthermore, a 75 mm layer of mason sand was spread uniformly over the top of the lysimeters. Perimeter irrigation systems were installed on each of the main plots. The irrigation system comprised of 24 mm diameter Schedule 40 PVC pipe with rotor Rainbird 3500 sprinklers placed in each corner adjusted to spray an inward quarter circle. Following the completion of the installation of the lysimeters St. Augustinegrass was planted in the designated plots. Before the actual initiation of the experiment, grass was allowed to establish for a period of 6 months. Thereafter, percolate water volume was measured and subsamples were collected (20 ml scintillation vial) at least weekly, and more frequently following precipitation events exceeding 25 mm. Additionally irrigation water and rain water samples were collected bi weekly as well. The subsamples, irrigation and rain samples were immediately preserved with one drop of 50% sulfuric acid to a pH < 2, refrigerated to a temperature < 4 °C and analyzed within 28 days as per Florida Department of

Environmental protection protocol. Percolate samples were analyzed by colorimetric method for NO_3-N (EPA method 353.2) using a Seal AA3 continuous flow analyzer (Seal Analytical Mequon, WI) by the University of Florida Analytical Research Laboratory (Gainesville, FL). In addition, percolate samples were analyzed for ammonium (NH_4-N) by colorimetric method (QuickChem method 10-107-06-2-A) using a Lachat Flow injection analyzer (Hach Company, Loveland, CO) at the Everglades Research and Education Center, University of Florida. All values below the minimum detection limit (MDL) were reported as the MDL. Minimum detection limits for NO_3-N and NH_4-N methods were 0.05 and 0.05 mg/L for trial 1 and 0.15 and 0.05 mg/L for trial 2, respectively. Total quantity of NO_3-N and NH_4-N leached and flow weighted means concentrations (total quantity of N leached/total volume percolate) were calculated from volume of percolate and laboratory analyses for each cycle.

Analysis of Data

All data were analyzed for normality using the Shapiro-Wilk W test. Homogeneity of variance was also checked graphically. Percolate, NO_3-N and NH_4-N leached were summed on a plot-by-plot basis for each year and analyzed on a yearly basis. In addition, mean flow weighted concentrations were calculated for each trial. All data were subjected to analysis of variance with PROC Mixed (SAS Institute, 1999) and means were separated using fisher’s protected Least Significant Difference (LSD) test with alpha=0.05. Orthogonal contrasts examined linear and quadratic responses to N rates (Gomez and Gomez, 1984).

Results

Hydrology

Annual rainfall for trial 1 and 2 averaged 1658 and 1538 mm, respectively (Figure, 2-1). Rainfall in trials 1 and 2 accounted for 67 and 46% and 65 and 43% of total inputs for the low and high irrigation regimes, respectively. Irrigation inputs for the low and high irrigation regime averaged 807 and 1892 mm for trial 1 and 877 and 2173 mm for trial 2, respectively. Total water inputs varied depending on the irrigation regime. In trial 1 the high irrigation regime had a total water input of 3550 mm, which was 44% greater than water inputs for the low irrigation (2465 mm). Similarly, in trial 2 the high irrigation regime had 52% (3811 mm) greater water inputs than the low irrigation (2515 mm) (Figure, 2-1). Drainage was ($P < 0.05$) impacted by irrigation regime and N rates (Table 2-2). In both trials, the greatest drainage occurred from the high irrigation regime with means of 1702 and 1720 mm for trials 1 and 2, respectively. The low irrigation regime resulted in 37 and 28% less drainage than the high irrigation regime for the same trials. Under high and low irrigation regimes 49 and 51 % of the total water inputs were lost as drainage in trial 1 and 45 and 48% for trial 2, respectively. Furthermore, in both trials as N increased drainage generally decreased. In trial 1 and 2 drainage decreased from 1588 to 1397 mm and 1569 to 1336 mm in response to N rates increasing from 98 to 588 kg N ha^{-1} yr^{-1} (Table 2-2).

Nitrogen Leaching

Nitrate-N and NH_4-N concentrations in the rain and irrigation water were always below the MDLs for their respective trials. Flow weighted (FW) NO_3-N concentrations in the drainage were similar ($P > 0.05$) among both irrigation regimes and nitrogen rates (Table 2-2). Flow weighed (NO_3-N) concentrations in the leachate from the low and high irrigation treatments averaged 0.21 and 0.17 mg L^{-1}. Similarly, FW (NO_3-N) concentrations in the leachate from the N treatments ranged from 0.15-0.28 mg L^{-1}. In addition, FW (NH_4-N) concentrations in the drainage were always lower than the FW (NO_3-N) concentrations. Furthermore, increasing irrigation inputs (high irrigation regime) or N rates did not increase ($P > 0.05$) FW (NH_4-N) concentrations in drainage. Flow weighted NH_4-N concentrations in the drainage averaged 0.07 and 0.08 mg L^{-1} for the low and high irrigation regimes, respectively (Table 2-2). Flow weighted (NH_4-N) concentrations leached from the different fertilizer rates ranged from 0.07-0.09 mg L^{-1} with FW (NH_4-N) concentrations never exceeded a mean value of 1 mg L^{-1}.

Total inorganic nitrogen (TIN) leached was not ($P > 0.05$) affected by irrigation regimes or N rates (Table 2-2). However, the high irrigation regime always produced the greatest amounts of TIN leached with mean of 3.4 kg N ha^{-1}. Additionally, the high irrigation regime accounted for 42 % more TIN leached compared to the low irrigation regime. Total inorganic N leached from the different fertilizer rates ranged from 2.2 to 3.8 kg N ha^{-1} (Table 2-2). The highest N rate always produced the greatest amount of TIN leached with mean of 3.8 kg N ha^{-1}. Under the highest N rate TIN leached represented less than 0.6% of the total N applied. Similar to TIN leached, NO_3-N leached was not ($P > 0.05$) affected by irrigation or N rates (Table 2-2). However, the high irrigation regime and highest N rate produced the greatest quantity of NO_3-N and NH_4-N leached. Under the high irrigation regime averaged NO_3-N and NH_4-N leached were 1.8 and 1.1 kg N ha^{-1}. In addition, under the highest N rate the average NO_3-N and NH_4-N leached were 3.1 and 0.7 kg N ha^{-1}(Table 2-2).

Discussion

Irrigation regimes and N rates were evaluated for N leaching on a sand rootzone. A rate of 588 kg N ha^{-1} was included, which is twice the recommended rate for St Augustinegrass in south Florida, to serve as a worst-case scenario. Throughout the duration of the experiment flow weighted (NO_3-N) leached levels never elevated above the EPA human health standards of 10 mg NO_3-N L^{-1}. The highest FW concentration measured in the drainage water was never > 4 mg NO_3-N L^{-1}. Irrigation regimes and N rate did impact drainage, and N rate affected FW NO_3-N concentrations in the drainage (Table 2-2). However, the quantities of NO_3-N, NH_4-N or TIN leached did not differ among any of the treatments. These results raise questions as to whether ordinances are really needed to reduce the N applied beyond that enforced by the Urban Turf Fertilizer Rule, which limits N applications to 49 kg N ha^{-1} of which, the water-soluble N portion should not exceed 34 kg N ha^{-1}.

Drainage was greatly impacted by irrigation regime, as the high irrigation regime increased drainage by an average of 39%. However, FW NO_3-N and NH_4-N concentrations did not differ under the high irrigation regime. Despite greater drainage, with the high irrigation regime, we found no differences in the quantity of NO_3-N, NH_4-N or TIN leached, due largely to the fact that concentrations tended to be lower in the high irrigation regime compared to the low irrigation regime (Table 2-2). This may be attributed to the high irrigation diluting the NO_3-N and NH_4-N concentrations in the drainage water especially if NO_3-N and NH_4-N concentrations are low in the soil solution. Furthermore, in both studies, FW NO_3-N concentrations were greater than NH_4-N concentrations. This may be explained by urea being rapidly converted to NO_3-

N through the processes of hydrolysis and nitrification and/or by NH_4-N being retained on the cation exchange site thus, being less mobile than the NO_3-N.

The results in this study with regard to irrigation effects on N leaching differ from many published studies (e.g., Morton et al., 1988; Snyder et al. 1984, and Barton et al., 2006). For example, Barton et al. (2006) found that increasing the irrigation from 70% to 140% of ET increased N leaching significantly. However, in this study increasing total water inputs by 48% did not significantly increase FW NH_4-N or NO_3-N concentrations or quantities leached, but there was a general trend in this direction, indicating that irrigation in the present study was not as excessive as earlier reported research. Nitrogen rates did impact drainage and FW NO_3-N concentrations. Higher N rates generally decreased drainage due to the increase in growth rates that increased water use rates (McGroary et al., 2010) thus, decreasing the drainage volume. Barton, (2009) found similar results when increasing N rate increased ET rates. Furthermore, Snyder et al., 1984 showed that reducing percolate reduced N leaching from bermudagrass. Thus, a well maintained lawn (proper irrigation and fertilization) may actually reduce leaching due to the reduced percolate through the rootzone. In general, as N rate increased so did FW NO_3-N concentrations. Again, these differences did not result in ($P > 0.05$) greater FW NO_3-N, NH_4-N or TIN leaching, due to the less drainage observed with the high N rates. Nevertheless, there was a trend towards greater TIN leaching at the high N rates. However, it’s possible that greater quantities of the applied N could be leached as urea or loss through gases losses. Unfortunately in this study organic-N in percolate or gaseous losses were not measured. Thus, we were unable to predict how much total N from urea was leached or lost to the atmosphere, but Sartain

(2010) reported that urea applications to St. Augustinegrass at 49 kg N ha^{-1} every 30 days for a period of 180 days did not produce urea in leachates.

Consequently, in this study we only examined the impact of N rates on TIN. Total inorganic N leached accounted for less than 3% of the total applied N lost. This advocates that alternative pathways in the N cycle played a more significant part in the fate of N in this system. The amount of N leached has been found to be dependent on soil storage/drainage, amount of N in solution, gaseous losses (volatilization and denitrification), immobilization, and N uptake by the vegetation. The results indicated that St. Augustinegrass was either efficient at removing the NH_4-N and NO_3-N from the soil solution or at tying them up through immobilization, as soil storage in the ionic form would have been negligible due to low cation exchange capacity of the soil. Additionally, the N applied may have been lost to the atmosphere through volatilization or denitrification or a combination of both pathways. In order to minimize N volatilization losses in this study 13 mm of irrigation was applied immediately after N fertilization, which Bowman et al. (1987), reported to reduce volatilization to less than 8% from Kentucky bluegrass (*Poa pratensis* L.). However, irrigation application after N fertilization may have not been adequate at halting volatilization completely. With the soil having a pH 7.8 and environmental conditions (high temperature and humidity) this would have been conducive for volatile N loss especially if irrigation was ineffective at initially reducing volatilization (Titko et al. 1987). Plots receiving higher rates of N are prone to higher rates of ammonium volatilization than the lower N rates (Wesley et al., 1987). Additionally, denitrification a pathway by which facultative anaerobes reduce NO_3-N to molecular N in anaerobic soils (Coyne, 2008) may have contributed to N loss.

Horgan et al., (2002) reported 9.8 kg N ha^{-1} loss of applied N from Kentucky bluegrass through denitrification. However, Barton et al. (2006) reported low denitrification rates in sands, thus accounting for only a small amount of N loss. Immobilization, the conversion of inorganic N to organic N, may also contribute to a large disparity between N applied and leached. Starr and Deroo (1981) evaluated the fate of N on cool-season grasses using labeled 15N and found that 15 – 21% of applied N was stored in the organic content of the soil. However, plant uptake may have had the greatest impact of reducing N leaching in this study. Bowman et al., (2002) reported that St Augustinegrass was relatively efficient at reducing NO_3-N leaching due to its root length density when compared to common bermudagrass [*Cynodon dactylon* (L.) Pers.], 'Tifway' hybrid bermudagrass (*C. dactylon* X *transvaalensis*), centipedegrass (*Erem chloaophiuroides* (Munro) Hack.), 'Meyer' zoysiagrass (*Zoysia japonica* Steud.), and 'Emerald' zoysiagrass (*Z. japonica X* in*tenuifolia*)].

Furthermore, Bowman et al. (2002) reported that shoots, clippings and roots accounted for up to 74% of applied N with the greatest quantity being stored in the shoots (52%). Unfortunately, in this study, shoots were not measured but this may help explain why little N leaching occurred.

Conclusion

Under worse case scenario conditions such as a sand rootzone and double the recommended N rate, N leaching was negligible and did not exceed human health standards or those thought to be of concern for environmental impact. Therefore, the are no need to reduce N application rates beyond the current Urban Turf Fertilizer Rules. Furthermore, the high irrigation regime (3 X week) did not significantly increase N leaching from St. Augustinegrass. However, it produced more drainage, which indicated that irrigating at a greater rate but reduced frequency may actually be a poor management strategy for conserving water compared to a lower irrigation rate increased frequency irrigation regime.

Figure 2-1. Irrigation and precipitation inputs for the low and high irrigation regimes for trial 1 and trial 2 (n = 32).

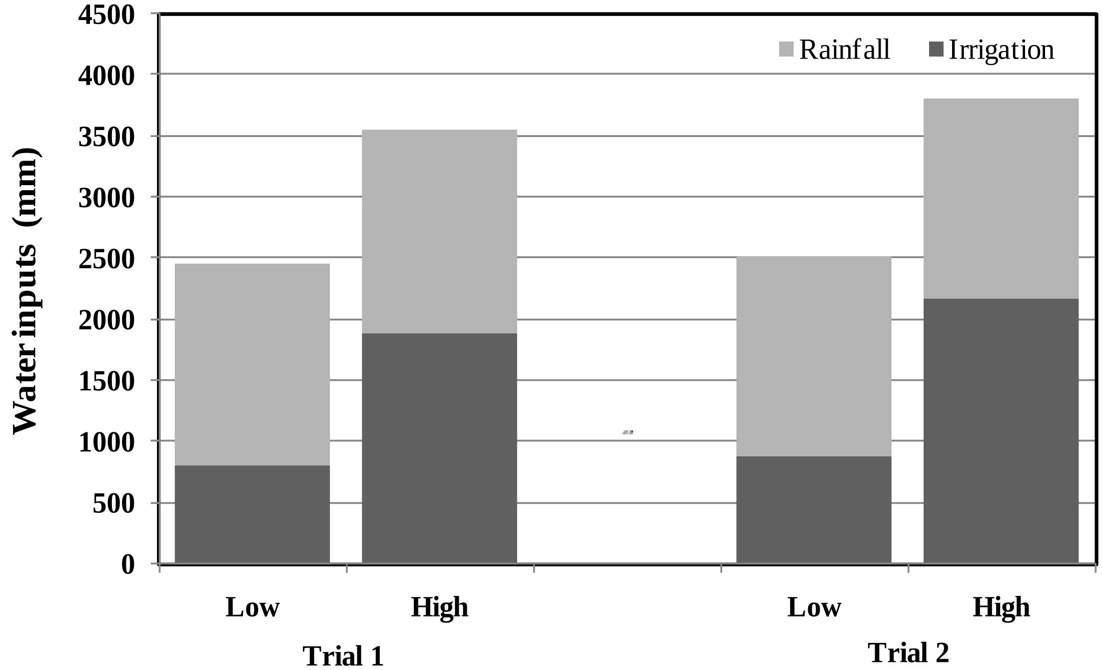

Table 2-1. Percentage by weight of mineral particle fractions contained in the root zone used for construction of the field study area.

Name	Size range	Weight
	--------mm------	----%----
Fine Gravel	2.0 - 3.4	0
Very coarse sand	1.0 - 2.0	2
Coarse sand	0.5 - 1.0	7
Medium sand	0.25 - 0.50	23
Fine sand	0.15 - 0.25	27
Very Fine Sand	0.05 - 0.15	34
Silt	0.002 - 0.05	7
Clay	less than 0.002	0

Table 2-2. Analysis of variance results for drainage, flow-weighted concentration f NO_3-N, flow-weighted concentration of NH_4-N quantity of NO_3-N leached, quantity of NH_4-N leached and, quantity of total inorganic N leached. Treatment means represent the average of 4 plots.

Effects	Drainage (mm)	[NO_3-N] (mg L^{-1})	[NH_4-N] (mg L^{-1})	NO_3-N leached (kg ha^{-1})	NH_4-N leached (kg ha^{-1})	Inorganic-N leached (kg ha^{-1})
Irrigation (IRR)						
Low	1231	0.21	0.08	1.8	0.6	2.4
High	1711	0.17	0.07	2.3	1.1	3.4
Nitrogen Rate (NR) (kg ha^{-1} yr^{-1})						
98	1579	0.15	0.07	1.6	0.6	2.2
196	1556	0.18	0.07	2.0	0.6	2.6
294	1378	0.16	0.08	1.6	0.6	2.2
588	1367	0.28	0.09	3.1	0.7	3.8
	ANOVA					
Source of variation						
TRIAL	NS	NS	NS	NS	NS	NS
IRR	*	NS	NS	NS	NS	NS
NR	**	*	NS	NS	NS	NS
Linear	NS	*	NS	NS	NS	NS
Quadratic	**	NS	NS	NS	NS	NS
IRR x NR	NS	NS	NS	NS	NS	NS
TRIAL x IRR x NR	NS	NS	NS	NS	NS	NS

NS, *, and ** = P > 0.05, P < 0.05, and P < 0.01, respectively. Note: Interactions not shown were not significant.

CHAPTER 3
EFFECTS OF IRRIGATION REGIMES AND NITROGEN FERTILIZATION ON ST. AUGUSTINEGRASS GROWTH QUALITY AND WATER CONSERVATION

Introduction

St. Augustinegrass (*Stenotaphum secundatum* [Walt.] Kuntze) is one of the most widely used grass species for home lawns in the Southeastern United States. In Florida alone, St. Augustinegrass is grown on approximately 70% of the lawns with an additional 24,164 ha grown for sod production (Busey, 2003; Haydu et al., 2005). St. Augustinegrass is adapted for moderate cultural practices, which include judicious inputs of both N and irrigation (Trenholm et al., 2000). Irrigation and N are essential components of producing quality turfgrass (Beard, 1973). At the appropriate rates, N and irrigation have been shown to improve turfgrass color, quality, and root growth along with many other additional benefits. However, excess N and irrigation rates applied to turfgrass can potentially increase NO_3-N leaching and degrade water quality (Hull and Liu, 2005; Snyder et al., 1984).

In addition, many state regulators have criticized St. Augustinegrass management both for its high water use in home yards, as a recent study showed that irrigation accounted for 64% of residential water use (approx. 141 mm mo^{-1}) in Central Florida (Haley et al., 2007). As a result, many municipalities across the nation have enacted water and N fertilizer restrictions to limit residential inputs in order to conserve water and protect water resources (e.g., SFWMD, 2010). Some municipalities even offer rebates to remove grass and replace it with xeriscape (Glendale, 2010). For example, in south Florida the SFWMD enforces different phases of water restrictions to landscapes and golf courses in order to conserve water. These phases can limit irrigation from three days per week (Phase 1) to once a week (Phase 3) or none (SFWMD, 2010) depending on the ordinance and water restriction in place. These efforts are intended to conserve water and result in penalties that are enforced if caught watering outside the guidelines. Currently, the state is in mandatory Phase 1 to Phase 3 restrictions year round. Other municipalities prohibit planting of St. Augustinegrass (Central Florida) or do not permit irrigation from installed irrigation systems in South West Florida.

Because of concerns over anthropogenic inputs of N to threatened water bodies, such as coastal bays and fresh water systems (Vitousek et al., 1997), current state-wide regulations in Florida under the Urban Turf Fertilizer Rule limit N applications to 49 kg N ha^{-1} of which, the water-soluble N portion should not exceed 34 kg N ha^{-1} (Department of Agricultural and Consumer services (DACS), No. 4640400, Rule 5E-1.003, 2007). However, there are no published data on whether these management practices actually conserve water or provide sufficient N nutrition to maintain acceptable St. Augustinegrass in South Florida that are grown primarily on sandy soils with little ability to retain water and nutrients. Research is needed to determine if such practices can actually conserve water and maintain St. Augustinegrass quality. Furthermore, data is lacking on the minimum N inputs required in order to produce acceptable St. Augustinegrass in south Florida. Consequently, research must be conducted to provide accurate fertilizer recommendations so acceptable turfgrass quality can be maintained with minimum impact on the environment.

Therefore, the objectives of this experiment were to 1) evaluate irrigation and fertilizer practices and their impact on water conservation and St. Augustinegrass growth and quality 2) to evaluate an alternative irrigation regime and to determine minimum N requirements for the production of St. Augustinegrass in subtropical south Florida.

Materials and Methods

The study was conducted at the University of Florida's Institute of Food and Agricultural Sciences (IFAS), Fort Lauderdale Research and Education Center (26°03' N, 80°13' W) on an established mature stand of St. Augustinegrass cv. 'Floratam' sod initially produced on sand soil and then grown on a mined 'mason' sand commonly-used in landscapes in south Florida. The sand was low (<0.5%) in organic matter (OM) (Table 1) and had a pH of 7.9 ± 0.2. The experiment consisted of 32 plots in a split-plot randomized complete block design with four replications of each treatment. Main blocks (8 x 4 m) consisted of one of two irrigation regimes: 2.5 mm daily (Low) except when daily precipitation > 6.4 mm (irrigation turned off), and 13.0 mm three times weekly (High) simulating a Phase 1 water use restriction that is implement by the South Florida Water Management District under water shortages (SFWMD, 2010). The irrigation system comprised of 24 mm diameter Schedule 40 PVC pipe with rotor Rainbird 3500 sprinklers placed in each corner adjusted to spray an inward quarter circle. Subplots (2 x 4 m) consisted of four N rates (98, 196, 294 and 588 kg N ha^{-1} yr^{-1}). The 588kg N ha^{-1} $yr^{-1)}$ which included in the study as a worst case scenario for excessive N applications to home yards in south Florida which is double the recommend rate for N in this geographical region (Trenholm et al., 2000). The 294 kg rate is suggested for south Florida conditions with appreciable soil organic matter, and 196 kg is more comparable to central/north Florida with a shorter growing season. The 98 kg rate is recommended for the University of Florida "Florida Yards and Neighborhood" resource efficient landscapes that include turf. Nitrogen rates were split equally over 6 application dates in 2006-2007 except for (cycle two and three) in trial 1 and again in 2007-2008 trial 2. In 2006-2007 N was applied on the 12 Oct., 12 Dec. 2006 and 15 Mar., 17 Apr., 18 June, and 16 Aug. 2007. In 2007-2008, N was applied on the 11 Oct., 21 Dec. 2007 and 20 Feb., 21 Apr., 23 June, and 3 Sept. 2008. Each application date represented the start of a new fertilizer cycle (FC). Spray grade granular urea (46-0-0) was used as the source of N and applied with a backpack CO_2-pressurized (30 psi) sprayer equipped with two flat-fan TeeJet 8010 nozzles on 510 mm spacing as per industry standard method of application. Immediately following N applications, plots received 13 mm of irrigation to reduce loss by volatilization and reduce burn potential (Bowman et al., 1987). In addition to N fertilization, P and K from triple superphosphate (0-46-0) and muriate of potash (0-0-60) were applied to maintain acceptable soil test values at the rate of 196 and 392 kg ha^{-1} yr^{-1}, split equally every 90-d, respectively. Additionally, micro-nutrients were applied as Harrell's Max Minors® containing Mg 1%, S 3.5%, B 0.02%, Cu 0.25%, Fe 4%, Mn 1%, Zn 0.6% and Mo 0.0005% at 12 L ha^{-1} every 90-days. Plot were maintained using a rotary mower at a height of cut of 75 mm and clippings were removed.

Turfgrass Quality

Irrigation and N response was evaluated in terms of visual quality. Visual quality evaluations were conducted approximately every 14 days and ratings were based on a scale of 1-9, where 1 was brown or dead grass and 9 represented dark green, dense uniform grass. A rating of 6.5 was considered minimally acceptable (Carrow, 1997). Turfgrass clipping samples for shoot growth were harvested from a 2.24 m^2 area within each plot using a rotary mower (Toro, Bloomington, MN) set at a height at a 75 mm approximately bi-weekly or more frequently when necessary. Samples were oven dried at 80^{o} C for 48 hrs to a constant weight. Subsequently, tissue samples were ground using a Wiley Mill and sub sampled for tissue N analysis. Nitrogen was determined using a modification of digestion described by Wolf (1982) and analyzed for NH_4-N using a spectrometer (UNIVO 2100, Dayton, NJ) at a wavelength of 660 nm. Nitrogen uptake was calculated by multiplying tissue N concentration (g N kg^{-1}) by yield (kg dry wt. ha^{-1}), and was reported as g N ha^{-1}. Reference evapotranspiration was calculated using a modified penman method and was obtained from a Florida Automated Weather Network (FAWN) station which was located within 500 m of the test site (Zazueta, 1991).

Statistical Design and Analysis

All data were analyzed for normality using the Shapiro-Wilk W test. Homogeneity of variance was also checked graphically. Turfgrass quality, clipping yields (CYs), tissue N concentration, and N uptake were summed on a plot-by-plot basis for each cycle and analyzed on a year bases because of trial by treatment interactions. All data were subjected to analysis of variance with PROC Mixed (SAS Institute, 1999) and means were separated using Fisher's protected Least Significant Difference (LSD) test with alpha=0.05. Orthogonal contrasts examined linear and quadratic responses to N rates (Gomez and Gomez, 1984).

Results

Hydrology

The relative contribution of irrigation and rainfall differed depending upon the time of year and irrigation regime (Table 3-2). For the dry season cycles (i.e., FC1, FC2, and FC3) low and high irrigation regimes accounted for between 48 to 59 % and 67 to 77%

of the total water received by plots for trial 1 and 35 to 49% and 58 to 69% for trial 2 (Table 3-2). However, for the wet season cycles (i.e., FC4, FC5, and FC6) irrigation inputs accounted for considerably less of the total inputs with low and high irrigation regimes accounting for between 19 to 34% and 39 to 57% of the water received by plots for trial 1, and 20 to 48% and 42 to 68% for trial 2 (Table 3-2). The large differences between seasons in the percent of total inputs that irrigation accounts for can be explained by the large precipitation event that normally occurs in the wet season in Florida (Table 3-2). In addition, the dry season low and high irrigation regimes alone accounted for between 65 to 109% and 147 to 251% of ET rates for trial 1 and 62 to 119% and 162 to 281% of ET rates for trial 2. However, for the wet cycles low and high irrigation regimes account for between 49 to 50% and 126 to 138% of ET rates for trial 1 and 44 to 70% and 118 to 172% for trial 2 (Table 3-2). Irrigation inputs for the high irrigation exceed the low irrigation regime by 144% (1162mm) and 148% (1296 mm) for trial 1 and 2 respectively. Throughout the duration of both trials total inputs (rainfall + irrigation) always exceeded ET demands of St. Augustinegrass. For the dry season low and high irrigation total inputs exceed ET rates by 36 to 116% and 118 to 258% for trial 1 and 79 to 145% and 179 to 307% for trial 2. During the wet season low and high irrigation total inputs exceed ET rates by 44 to 164% and 121 to 253% for trial 1 and 4 to 147% and 72 to 249% for trial 2.

Turfgrass Quality

St Augustiengrass visual quality was affected (*P* > 0.05) by irrigation regimes though not significant in every cycle (Tables 3-3, 3-4). Both irrigation regimes did produce acceptable quality (≥ 6.5) for the duration of both trials (Tables 3-3, 3-4). Throughout the duration of trial 1, low and high irrigation regimes produced similar turfgrass quality with an average score of 7.0 for both irrigation regimes. However, in trial 2 the high irrigation regime produced higher visual quality rating than the low irrigation regime with average scores of 6.7 and 6.6, respectively (Table 3-4).

Nitrogen rates affected turfgrass quality ratings with visual quality increasing with N rate in both trials (Tables 3-3, 3-4). Among the four N rates evaluated only 98 kg N ha^{-1} yr^{-1} was unable to produced acceptable (≥ 6.5) visual quality for the duration of both trials with the 588 kg N ha^{-1} yr^{-1} always producing the highest quality with means of 7.8 and 7.6 for trial 1 and 2. Furthermore, plots receiving 294 kg N ha^{-1} yr^{-1} always yielded higher visual quality ratings than the 196 kg N with average scores of 7.1 and 6.7 and 6.8 and 6.6 for trial 1 and 2, respectively. The lowest quality scores were observed at the 98 kg N ha^{-1} yr^{-1} which had average visual scores of 6.3 and 5.8 for trial 1 and 2 which was below the acceptable (≥ 6.5) visual quality (Tables 3-3, 3-4).

Clippings Yield

Results for CYs were similar to those for visual quality. Clipping yields generally increased by N rate (Tables 3-5, 3-6). Greatest CYs occurred from plots receiving 588 kg N ha^{-1}, which typically yielded twice as much clipping as the plots receiving the next highest N rate of 294 kg N ha^{-1} (Tables 3-5, 3-6). No differences in CYs were observed between plots receiving 294, 196, and 98 kg N ha^{-1} when averaged over each trial. However, statistical differences were observed between N rates within each cycle. Plots receiving the higher N rate always produced the greatest CYs except FC4 in trials 1 and 2. Plots receiving 98 kg N ha^{-1} generally produced about 35% less clippings than plots receiving 196 kg N ha^{-1}. Similar CYs were observed from plots receiving 294 and 196 kg N ha^{-1}. Irrigation regimes had no effect on CYs (Tables 3-5, 3-6).

Tissue N

Irrigation regime had no effect (*P* > 0.05) on tissue N concentration (Tables 3-7, 3-8). The N concentration of clippings generally increased with increasing N fertilization rates. However, N fertilization only affected tissue N levels in 4 cycles in trial 1 and 3 cycles in trial 2. The N rate of 588 kg N ha^{-1} always produced the highest N concentration with average tissue concentrations of 21.3 and 20.5 g N kg^{-1} for trials 1 and 2, respectively. Though, tissue N did vary between cycles with N ranging from 18.9 to 26.4 g N kg and 18.0 to 24.5 g N kg for trials 1 and 2. The lowest tissue N was always found on the plots receiving 98 kg N ha^{-1} with an average tissue N of 17.1 and 17.9 g kg^{-1} for their respective trials (Tables 3-7, 3-8).

Nitrogen Uptake

Nitrogen uptake was greatly influenced by N fertilization (Tables 3-9, 3-10). As nitrogen rates increased so did N uptake. However, only the 588 kg N ha^{-1} rate was statistically different from the other three N rates averaged over each trial with the 588 kg N ha^{-1} rate almost taking up double the amount of N compared to the 298 kg N ha^{-1}. The 98 kg N ha^{-1} had the lowest N uptake with an average of 16 and 17 kg N ha^{-1} for trials 1 and 2, respectively. In addition, plots receiving N rates of 294 and 196 kg N ha^{-1} up took twice as much N as the 98 kg N ha^{-1}. However, it was statistically different in FC2 in trial 1 and FC1 and FC6 in trial 2. Similar N uptake was observed from plots receiving 294 and 196 kg N ha^{-1}. Nitrogen recovered in tissue based on percentage-applied range from 14 to 16% in trial 1 and 12 to 17% of applied in trial 2. The greatest % N recovery always occurred in the lowest N rate and the lowest recovery from the 294 kg N ha^{-1}. Irrigation regime had no significant effect on N uptake within each trial or when averaged across each trial (Tables 3-9, 3-10). Total N uptake for low and high irrigation regimes were 47.7 and 44.0 kg N ha^{-1} for trial 1 and 39 and 41 kg N ha^{-1} for trial 2.

Discussion

With water and N inputs to urban landscapes under scrutiny, it is essential that both are applied to match the needs of turfgrass, as this has been shown to help conserve water, reduce nitrogen leaching and produce aesthetically pleasing yards (McGroary, 2010). Currently, the SFWMD enforces mandatory water restrictions, whereby irrigation is limited between three times a week (phase 1) and once a week (phase 3). In this study two irrigation regimes and four N rates were compared to determine the most suitable irrigation regime and N rates to produce a visually acceptable St. Augustinegrass lawn with minimum inputs.

In the current study, the high irrigation regime, which is a phase 1 water restriction, did not improve growth, N uptake, and N concentrations. Barton et al. (2006) reported similar results, as increasing irrigation from 70% to 140% replacement of pan evaporation did not improve growth or quality of turfgrass. Under the high irrigation regime, irrigation far surpassed water requirements for St. Augustinegrass by at least about 65% thus, proving to be an ineffective way of conserving water as well as having little positive impact on quality. Furthermore, the greatest difference between the irrigation inputs and ET was observed during FC1, FC2 and FC3. Theses cycles occurred during the dry season in south Florida where lower temperatures generally reduced St. Augustinegrass growth and ET rate. However, under a phase one-water restriction no reduction in irrigation inputs would be carried out, thus leading to irrigation inputs greater than St. Augustinegrass demands with wasted water. On the other hand, the low irrigation regime did provide irrigation inputs closer to ET demands though when combined with rainfall did surpass water demands of the St. Augustinegrass. Nevertheless, during the dry season this irrigation regime conserved more water without sacrificing turfgrass quality. However, during cycles FC4, FC5 and FC6, the low irrigation regime did not match ET requirements, which Snyder, 1984 showed improve growth, N uptake and color of bermudagrass. When irrigation was combined with rainfall, the total water inputs were greater than the ET demand but had an irrigation savings of 588 and 653 mm over the high irrigation regime with still being able to produced similar turfgrass quality scores. These results suggest that the low irrigation regime may be a more suitable regime than the phase 3 restrictions which is enforced by the SFWMD for maintaining acceptable St. Augustinegrass quality in south Florida quality due to the fact that acceptable quality was able to be maintained while over 1162 and 1296 mm of irrigation water were conserved for trial 1 and 2 respectively (Table 3-2). In addition, N concentration, N uptake and growth were not affected by irrigation regime, indicating that neither irrigation regimes differed in the availability of N to the plant by moving it beyond the root system, and thus increasing the risk for N to be leached into the groundwater.

St Augustiengrass quality, N concentration, uptake and growth were greatly influenced by N rate. Nitrogen concentration values in this study were comparable to others found for St. Augustinegrass in the literature. For example, Broschat and Elliott (2004) report 13.0 to 19.7 g N kg^{-1} in St. Augustinegrass maintained with 196kg N ha^{-1}. In comparison, Vernon et al., (1993) documented 14 g N kg^{-1} in leaf clippings from St. Augustinegrass var. Raleigh.

Nitrogen concentration, quality, uptake and growth increased with increasing N rates. Nitrogen applications of 588 kg ha^{-1} application to St. Augustinegrass 588 kg ha^{-1} produced the best quality, greatest N concentration and N uptake but also produced the greatest amount of clippings compared to the other N treatments. However, this N rate may not be favored by homeowners as it greatly increases fuel, labor costs and waste disposal of clippings (Fluck and Busey, 1988). The N rate of 98 kg N ha^{-1} was unable to produce acceptable quality of St. Augustinegrass for the duration of both trials, although the quality that was produced may be acceptable to some homeowners who do not demand their lawn to be dense and green all year round, and who do not want the extra cost of regular mowing and waste disposal. In addition, under different soils or management practices, such as returning clippings this N rate may be able to produce an acceptable yard, though further research is needed to validate this question. The minimum acceptable quality for St. Augustinegrass in South Florida could be reached by applying 196 kg N ha^{-1} as this was the lowest N rate that was able to produce minimum acceptable quality when average over each trial. However, this application rate did not always provide acceptable quality in all of the cycles, which may be unsatisfactory to some homeowners. But the N rate of 294 kg N ha^{-1} was always able to produced quality above minimum acceptable quality for all cycles and over each trial. Therefore, N recommendations of 196-294 kg N ha^{-1}, as currently recommended for South Florida (Trenholm et al., 2002), are accurate for maintaining St. Augustinegrass at acceptable levels with clippings being removed. These recommendations may be further reduced if clippings are returned rather than removed like in this study. Kopp and Guillard (2002) found that returning clippings could reduce fertilizer rates by 50% in cool-season turfgrass. Currently no such data exist for St. Augustinegrass, therefore research is needed to determine if N inputs could be further reduced by returning clippings to St. Augustinegrass.

In this study, the constructed soil was very low in organic matter, which can supply appreciable N for turfgrass growth. That coupled with the source of turf being derived from sand-based sod production probably had an effect on all measured parameters and demonstrate the need for more N nutrition under conditions of low OM, sand-based soil media with high saturated conductivity, and recently established turf. Over time, with increasing OM, perhaps improved turf quality with similar inputs could be expected. Although the irrigation rates were not excessive, since the N source was totally soluble, N pathways such as leaching and volatile losses could have impacted turf responses from the N fertilization. Research on more mature turf, soils with higher OM, and other N sources and application regimes along with irrigation regimes is needed.

Conclusion

While the results from this experiment varied across trials, some general conclusions can be drawn. The low irrigation was able to maintain St. Augustingrass quality throughout the duration of the experiment while conserving large amounts of water compared to the current implemented phase 1 restriction that are enforced in Florida. Nitrogen rate of 196 and 294 N/kg ha^{-1} yr^{-1} produced acceptable quality while not producing excess growth. With minimum acceptable St Augustinegrss quality in south Florida been able to be produced at 196 kg N/kg ha^{-1} yr^{-1}.

Table 3-1. Percentage by weight of mineral particle fractions contained in the root zone used for construction of the field study area.

Name	Size range	Weight
	--------mm------	----%----
Fine Gravel	2.0 - 3.4	0
Very coarse sand	1.0 - 2.0	2
Coarse sand	0.5 - 1.0	7
Medium sand	0.25 - 0.50	23
Fine sand	0.15 - 0.25	27
Very Fine Sand	0.05 - 0.15	34
Silt	0.002 - 0.05	7
Clay	less than 0.002	0

Table 3-2. Total rainfall, total irrigation inputs, and reference ET for each cycle of the study.

Study[a] Period	Irrigation Regime	Period	Rainfall	Irrigation	Total Inputs	Reference! ET
			----------------------------mm----------------------------			
2006-2007	Low	C1	97	142	240	135
	Low	C2	216	221	437	202
	Low	C3	86	79	165	121
	Low	C4	412	130	541	258
	Low	C5	248	130	378	262
	Low	C6	453	104	557	211
	Total		1512	806	2318	1189
	High	C1	97	330	428	135
	High	C2	216	508	724	202
	High	C3	86	178	264	121
	High	C4	412	330	742	258
	High	C5	248	330	579	262
	High	C6	453	292	745	211
	Total		1512	1968	3480	1189
2007-2008	Low	C1	210	178	388	179
	Low	C2	142	135	277	113
	Low	C3	257	137	394	220
	Low	C4	158	145	303	291
	Low	C5	439	112	551	257
	Low	C6	432	170	602	244
	Total		1638	877	2515	1304
	High	C1	210	419	629	179
	High	C2	142	318	460	113
	High	C3	257	356	613	220
	High	C4	158	343	501	291
	High	C5	439	318	757	257
	High	C6	432	419	851	244
	Total		1638	2173	3811	1304

[a]2006-2008 Cycle 1, 12 October 2006 to 11 December 2006; Cycle 2, 12 December 2006 to 14 March 2007; Cycle 3, 15 March 2007 to 16 April 2007; Cycle 4, 17 April 2007 to 17 June 2007; Cycle 5, 18 June 2007 to 15 August 2007; Cycle 6, 16 August 2007 to 10 October 2007;2007-2008 Cycle 1, 11 October 2007 to 20 December 2007; Cycle 2, 21 December 2007 to 19 February 2008; Cycle 3, 20 February 2008 to 20 April 2008; Cycle 4, 21 April 2008 to 22 June 2008; Cycle 5, 23 June 2008 to 02 September 2008; Cycle 6, 03 September 2008 to 5 November 2008.

! Reference evapotranspiraton was determined using the Penman method.

Table 3-3. Trial 1 treatment means (n = 4) for turfgrass quality for low and high irrigation regimes and four N application rates.

Effects	C1	C2	C3	C4	C5	C6	Ave
				1-9			
Irrigation (IR)							
Low	6.9	6.9	6.8	7.3	7.1	7.0	7.0
High	6.9	7.0	7.0	7.0	7.1	7.0	7.0
Nitrogen Rate (NR) ($kg\ ha^{-1}\ yr^{-1}$)							
98	6.2c	6.0c	6.2c	6.9	6.4d	6.4c	6.3c
196	6.8b	6.6c	6.5c	6.9	6.8c	6.8bc	6.7bc
294	7.0b	7.2b	7.1b	6.8	7.3b	7.1b	7.1b
588	7.5a	7.9a	8.0a	7.9	7.9a	7.8a	7.8a
				ANOVA			
Source of variation							
IR	NS	NS	NS	NS	NS	NS	NS
NR	***	***	***	NS	***	***	***
IR x NR	NS	NS	NS	NS	NS	NS	NS

NS, and *** = P > 0.05, P < 0.001.
† Values within a column followed by the same letter are not statistically different (LSD, *P*≤ 0.05).

Table 3-4. Trial 2 treatment means (n = 4) for turfgrass quality for low and high irrigation regimes and four N application rates.

Effects	C1	C2	C3	C4	C5	C6	Ave
				1-9			
Irrigation (IR)							
Low	7.0	6.6a	6.5	6.6	6.6a	6.5	6.6a
High	6.9	6.8b	6.5	6.7	6.7b	6.7	6.7b
Nitrogen Rate (NR) ($kg\ ha^{-1}\ yr^{-1}$)							
98	6.0c	5.4c	5.5c	5.9c	6.0b	5.6c	5.8c
196	6.8b	6.6b	6.3b	6.4bc	6.4b	6.3b	6.5b
294	7.0b	6.7b	6.6b	6.8b	6.7ab	6.8ab	6.8b
588	7.9a	8.2a	7.5a	7.5a	7.3a	7.4a	7.6a
				ANOVA			
Source of variation							
IR	NS	**	NS	NS	*	NS	*
NR	***	***	***	**	*	***	***
IR x NR	NS	NS	NS	NS	NS	NS	NS

NS, *, **, and *** = P > 0.05, P < 0.05, P < 0.01, P < 0.001.
† Values within a column followed by the same letter are not statistically different (LSD, *P*≤ 0.05).

Table 3-5. Trial 1 treatment means (n = 4) for dry weight of clippings for low and high irrigation regimes and four N application rates.

Effects	C1	C2	C3	C4	C5	C6	Total
	----------kg ha^{-1}----------						
Irrigation (IR)							
Low	52	113	128	363	925	742	2323
High	63	121	108	348	853	663	2156
Nitrogen Rate (NR) (kg ha^{-1} yr^{-1})							
98	36	49c	75b	121b	313c	287b	881b
196	48	82bc	104b	331b	720b	647b	1932b
294	56	124b	95b	296b	782b	651b	2004b
588	90	214a	130a	673a	1741a	1226a	4074a
	ANOVA						
Source of variation							
IR	NS	NS	NS	NS	NS	NS	NS
NR	NS	*	*	*	***	**	***
IR x NR	NS	NS	NS	NS	NS	NS	NS

NS, *, **, and *** = P > 0.05, P < 0.05, P < 0.01, P < 0.001.
† Values within a column followed by the same letter are not statistically different (LSD, $P \leq 0.05$).

Table 3-6. Trial 2 treatment means (n = 4) for dry weight of clippings for low and high irrigation regimes and four N application rates.

Effects	C1	C2	C3	C4	C5	C6	Total
	----------kg ha^{-1}----------						
Irrigation (IR)							
Low	156	ND	307	213	595	770	2041
High	141	ND	295	276	665	806	2183
Nitrogen Rate (NR) (kg ha^{-1} yr^{-1})							
98	49c	ND	65b	83b	306b	468c	971b
196	125bc	ND	225b	217b	533b	745bc	1845b
294	157b	ND	250b	207b	549b	814b	1977b
588	264a	ND	663a	471a	1130a	1125a	3653a
	ANOVA						
Source of variation							
IR	NS	ND	NS	NS	NS	NS	NS
NR	**	ND	***	**	**	**	**
IR x NR	NS	ND	NS	NS	NS	NS	NS

ns, *, **, and *** = P > 0.05, P < 0.05, P < 0.01, P < 0.001.
† Values within a column followed by the same letter are not statistically different (LSD, $P \leq 0.05$). ND = No data was collected during this cycle.

Table 3-7. Trial 1 treatment means (n = 4) for nitrogen tissue concentration for low and high irrigation regimes and four N application rates.

Effects	C1	C2	C3	C4	C5	C6	Ave
	----------------------------------			g kg^{-1}		----------------------------------	
Irrigation (IR)							
Low	18.7	22.2	14.9	16.4	20.9	19.5	18.8
High	18.5	23.3	16.2	16.4	20.8	19.4	19.1
Nitrogen Rate (NR) ($kg\ ha^{-1}\ yr^{-1}$)							
98	17.0	20.5b	12.6c	14.1c	19.1	19.0b	17.1c
196	18.3	20.5b	12.8c	15.3bc	21.0	19.6b	17.9bc
294	19.3	23.8ab	17.1b	17.2ab	20.8	18.9b	19.5ab
588	19.8	26.4a	19.7a	18.9a	22.4	20.4a	21.3a
				ANOVA			
Source of variation							
IR	NS	NS	NS	NS	NS	NS	NS
NR	NS	*	***	**	NS	***	***
IR x NR	NS	NS	NS	NS	NS	NS	NS

NS, *, **, and *** = P > 0.05, P < 0.05, P < 0.01, P < 0.001.
† Values within a column followed by the same letter are not statistically different (LSD, $P \leq 0.05$).

Table 3-8. Trial 2 treatment means (n = 4) for nitrogen tissue concentration for low and high irrigation regimes and four N application rates.

Effects	C1	C2	C3	C4	C5	C6	Ave
	----------------------------------			g kg^{-1}		----------------------------------	
Irrigation (IR)							
Low	22.0	ND	21.5	16.7	17.4	16.9	18.9
High	22.0	ND	22.3	16.7	17.5	16.9	19.0
Nitrogen Rate (NR) ($kg\ ha^{-1}\ yr^{-1}$)							
98	20.4c	ND	19.7c	16.0b	16.1	16.3	17.9c
196	21.7bc	ND	21.3bc	16.1b	17.5	16.3	18.6b
294	21.9ab	ND	22.0b	16.1b	17.1	16.9	18.7b
588	23.2a	ND	24.5a	18.0a	19.1	18.0	20.5a
				ANOVA			
Source of variation							
IR	NS	ND	NS	NS	NS	NS	NS
NR	*	ND	**	*	NS	NS	**
IR x NR	NS	ND	NS	NS	NS	NS	NS

NS, *, and **, = P > 0.05, P < 0.05, P < 0.01.
† Values within a column followed by the same letter are not statistically different (LSD, $P \leq 0.05$). ND = No data was collected during this cycle.

Table 3-9. Trial 1 treatment means (n = 4) for nitrogen uptake for low and high irrigation regimes and four N application rates.

Effects	C1	C2	C3	C4	C5	C6	Total
	------------------	------------------	------------------	kg ha $^{-1}$	------------------	------------------	------------------
Irrigation (IR)							
Low	1.1	2.9	2.1	6.7	20.5	14.5	47.7
High	1.3	3.4	1.9	6.3	18.2	12.9	44.0
Nitrogen Rate (NR) (kg ha^{-1} yr^{-1})							
98	0.6	1.2c	1.0b	1.6b	6.2b	5.5b	16.1b
196	1.0	1.9bc	1.6b	5.2b	16.1b	12.0b	40.0b
294	1.1	3.4b	1.6b	6.2b	16.3b	13.0b	40.0b
588	2.0	6.1a	3.7a	13.1a	38.8a	24.0a	87.7a
				ANOVA			
Source of variation							
IR	NS	NS	NS	NS	NS	NS	NS
NR	NS	***	*	**	***	**	**
IR x NR	NS	NS	NS	NS	NS	NS	NS

NS, *, **, and *** = P > 0.05, P < 0.05, P < 0.01, P < 0.001.
† Values within a column followed by the same letter are not statistically different (LSD, *P*≤ 0.05).

Table 3-10. Trial 2 treatment means (n = 4) for nitrogen uptake for low and high irrigation regimes and four N application rates.

Effects	C1	C2	C3	C4	C5	C6	Total
	------------------	------------------	------------------	kg ha $^{-1}$	------------------	------------------	------------------
Irrigation (IR)							
Low	3.6	ND	7.3	3.7	11.2	13.5	39.2
High	3.1	ND	7.0	4.8	12.5	13.8	41.2
Nitrogen Rate (NR) (kg ha^{-1} yr^{-1})							
98	1.0c	ND	1.4b	1.4b	5.8b	7.8c	17.3b
196	2.8bc	ND	5.3b	3.8b	10.1b	12.3bc	34.4b
294	3.4b	ND	5.6b	3.4b	9.7b	14.0b	36.1b
588	6.2a	ND	16.3a	8.4a	21.8a	20.4a	73.2a
				ANOVA			
Source of variation							
IR	NS	ND	NS	NS	NS	NS	NS
NR	***	ND	**	**	**	**	**
IR x NR	NS	ND	NS	NS	NS	NS	NS

NS, **, and *** = P > 0.05, P < 0.01, P < 0.001.
† Values within a column followed by the same letter are not statistically different (LSD, *P*≤ 0.05). ND = No data was collected during this cycle.

REFERENCES

Aronson, L.J., A.J. Gold, R.J. Hull, and J.L. Cisar. 1987. Evapotranspiration of cool-season turfgrasses in the humid Northeast. Agron. J. 79:901–905.

Barton, L., G. G. Y. Wan, R. P. Buck, and T.D. Colmer. 2006. Turfgrass (Cynodon dactylon L.) sod production on sandy soils: II. Effects of irrigation and fertilizer regimes on N leaching. Plant and Soil. 284:147-164.

Barton, L., G. G. Y. Wan, R. P. Buck, and T.D. Colmer. 2009. Nitrogen increases evapotranspiration and growth of a warm-season turfgrass. Agron. J. 101:17-24.

Baum, M. C., M. D. Dukes, and G. L. Miller. 2005. Analysis of residential irrigation distribution uniformity. J. Irrig. Drain. Eng., 131:336-341.

Beard, J.B. 1973. Turfgrass: science and culture. Prentice Hall, Englewood Cliffs, NJ.

Bowman, D.C., J.L. Paul, W.B. Davis, and S.H. Nelson. 1987. Reducing ammonia volatilization from Kentucky bluegrass turf by irrigation. HortScience 22:84–87.

Bowman, D.C., and L. Macaulay. 1991. Comparative evapotranspiration rates of tall fescue cultivars. HortScience 26:122–123.

Bowman, D.C., C.T. Cherney, and T.W. Rufty, Jr. 2002. Fate and transport of nitrogen applied to six warm season turfgrasses. Crop Sci. 42: 833-841.

Brian, I., Bravado, I I. Bushkin-Harav, and E. Rawiytz. 1981. Water consumption and growth rates of 11 turfgrass as affected by mowing height, irrigation frequency, and soil moisture. Agron. J. 73:85-90.

Broschat, T. K., and M. L. Elliott. 2004. Nutrient distribution and sampling for leaf analysis in St. Augustinegrass. Communication in Soil. Sci. and Plant Anal. v.35 no.15 and 16:2357-2367.

Busey, P. and B. J. Center. 1987. Southern chinch bug (Hemiptera: Heteroptera: Lygaeidae) overcomes resistance in St. Augustinegrass. J. Econ. Entomol. 80:608-611.

Busey, P. 2003. St. Augustinegrass. pp. 309-330. *In* Casler, M. D., and Duncan, R. R. (eds.) Biology, breeding, and genetics of turfgrasses. John Wiley & Sons, Inc, Hoboken, NJ.

Carrow, R.N. 1997. Turfgrass response to slow-release nitrogen fertilizers. Agron. J. 89:491-496.

Cisar, J. L., G. H. Snyder, and P. Nkedi-Kizza. 1991. Maintaining quality turfgrass and minimal nitrogen leaching. Univ. of Florida., Inst of Food and Agr. Sci. 273. University of Florida, Gainesville, FL.

City of Glendale. 2010. Water conservation - Landscape rebates - Existing home conversions. Available at http://glendaleaz.com/waterconservation/landscaperebates.cfm (verified 10 March 2010). City of Glendale City, Glendale, AZ.

Council of the City of Sannibel. 2007. Ordinance No. 07-003. http://www.sanibelh2omatters.com/fertilizer/PDF/Fertilizer_Ordinance.pdf.

. Coyne, M.S. 2008. Biological denitrification. p. 201-253. *In* J.S. Schepers and W.R. Raun (ed.)Nitrogen in agricultural systems. Agron. Monogr. 49. ASA, CSSA, and SSSA, Madison,WI.

DaCosta, M., and B. Huang. 2006. Minimum water requirements for creeping, colonial, and velvet bentgrasses under fairway conditions. Crop Sci. 46:81–89.

Danielson, R. E., W.E. Hart, C.M. Feldhake, and P.M. Haw. 1979. Water requirements for urban lawns. Colo. Completion Report to OWRT Project B-035-WYO. 91 p.

Davenport, D.C. 1965. Versatility of a small grass transpirometer. Univ. of Nottingham School of Agriculture Rep. 54-60 p.

Department of Agricultural and Consumer services, No. 4640400, Rule 5E-1.003. 2007.http://www.dep.state.fl.us/water/nonpoint/.

Easton, Z.M., and A.M. Petrovic. 2004. Fertilizer source effect on ground and surface water quality in drainage from turfgrass. J. Environ. Qual. 33:645-655.

Ebdon, J.S., and A.M. Petrovic. 1998. Morphological and growth characteristics of low- and high-water use Kentucky bluegrass cultivars. Crop Sci. 38:143–152.

Ebdon, J.S., A.M. Petrovic, and R.A. White. 1999. Interaction of nitrogen, phosphorus, and potassium on evapotranspiration rate and growth of Kentucky bluegrass. Crop Sci.39:209–218.

Erickson, J. E., J. L. Cisar, J. C. Volin, and G.H. Snyder. 2001. Comparing nitrogen runoff and leaching between newly established St. Augustinegrass turf and an alternative residential landscape. Crop Sci. 41:1889-1895.

Erickson, J. E., J. L. Cisar, G. H. Snyder, D. M. Park, and K. E. Williams. 2008. Does a mixed-species landscape reduce inorganic-nitrogen leaching compared to a conventional St. Augustinegrass Lawn? Crop Sci. 48:1586-1594.

Erickson, J. E., D. M. Park, J. L. Cisar, G. H. Snyder, and A. L. Wright. 2010. Effects of Sod Type, Irrigation, and Fertilization on Nitrate-Nitrogen and Orthophosphate-Phosphorus Leaching from Newly Established St. Augustinegrass. Crop Sci. 50:1030-1036.

Feldhake, C.M., R.E. Danielson, and J.D. Butler. 1983. Turfgrass evapotranspiration. I. Factors influencing rate in urban environments. Agron. J. 75:824–830.

Flipse, W.J., Jr., B.G. Katz, J.B. Linder, and R. Markel. 1984. Sources of nitrate in ground water in a sewered housing development. Central Long Island, New York. Ground Water. 32: 418-426.

Fluck, R. C. and P. Busey. 1988. Energy for mowing turfgrass. Trans. ASAE 31:1304-1308.

Fry, J.D., and J.D. Butler. 1989. Annual bluegrass and creeping bentgrass evapotranspiration rates. HortScience 24:269–271.

Fu, J., J. Fry, and B. Huang. 2004. Minimum water requirements of four turfgrasses in the transition zone. HortScience 39:1740–1744.

Geron, C. A., T. K. Danneberger, S. J. Traina, T. J. Logan, and J. R. Street. 1993. The effects of establishment methods and fertilization practices on nitrate leaching from turfgrass. J. Environ. Qual. 22(1):119-125.

Gomez, K. A., and A. A. Gomez. 1984. Statistical Procedures for Agricultural Research, 2nd Edition. John Wiley & Sons, Inc, NY.

Green, R.L., S.I. Sifers, C.E. Aitken, and J.B. Beard. 1991. Evapotranspiration rates of eleven Zoysia genotypes. HortScience 26:264–266.

Gross, C. M., J.S. Angle, and M.S. Welterlen. 1990. Nutrient and sediment losses from turfgrass. J. Environ. Qual. 19: 663-668.

Haley, M.B, M.D. Dukes, and G.L. Miller. 2007. Residential irrigation water use in Central Florida. Journal of Irrigation and Drainage Engineering 133:427-434.

Haydu, J. J., J.Cisar, and L.Satterthwaite. 2005. Florida's Sod Production Industry: A 2003 Survey. International Turfgrass Society Research Journal 10:700-704.

Horgan, B.P., B.E. Branham, and R.L. Mulvaney. 2002. Mass balance of ^{15}N applied to Kentucky bluegrass including direct measurement of denitrification. Crop Sci. 42:1595–1601.

Hull, R.J. and H. Liu**.** 2005. Turfgrass nitrogen: physiology and environmental impacts. International Turfgrass Society Research Journal. 10:962-975.

Kopp, Kelly L., and Karl Guillard. 2002. Clipping management and nitrogen fertilization of turfgrass: growth, nitrogen utilization, and quality. Crop Science. 42:1225-1231.

Kim, K.S., and J.B. Beard. 1988. Comparative turfgrass evaporation rates and associated morphological characteristics. Crop Sci. 28:328–331.

Kneebone, W.R., and I.L. Pepper. 1982. Consumptive water use by sub-irrigated turfgrasses under desert conditions. Agron. J. 74:419–423.

Kneebone, W.R., D.M. Kopec, and C.F. Mancino. 1992. Water requirement and irrigation. p. 441–472. In D. Waddington (ed.) Turfgrass. Agron. Monogr. 32. ASA, CSSA, and SSSA, Madison, WI.

Kopec, D.M., R.C. Shearman, and T.P. Riordan. 1988. Evapotranspiration of tall fescue turf. HortScience 23:300–301.

Mancino, C. F., and J. Troll. 1990. Nitrate and ammonium leaching losses from N fertilizers applied to 'Penncross' creeping bentgrass. HortScience 25: 194–196.

Mantell, A. 1966. Effects of irrigation frequency and nitrogen fertilization on growth and water use of a Kikuyugrass lawn (*Pennisetum clandestinum* Hochst.). Agron. J. 58:559–561.

Miltner, E.D., B.E. Branham, A.E. Paul, and P.E. Rieke. 1996. Leaching and Mass balance of 15N-labelled urea applied to a Kentucky bluegrass turf. Crop Sci. 36:1427-1433.

Morton, T.G., A.J. Gold, and W.M. Sullivan. 1988. Influence of overwatering and fertilization on nitrogen losses from home lawns. J. Environ. Qual. 17:124-130.

Miller, G.L, and L.B. McCarty. 2001. Water relations and rooting characteristics of three *Stenotaphrum secundatum* turf cultivars grown under water deficit conditions. International Turfgrass Society Research Journal. 9:323-327.

McCarty, L. B. and J. L. Cisar. 1995. Bahiagrass for Florida lawns. *In* L. B. McCarty, K. C. Ruppert, and R. J. Black, eds. Florida Lawn Handbook. Gainesville, FL: Florida Cooperative Extension Service.

McGroary, P. C. 2010. Nitrogen leaching, water use rates and turf response of St. Augustinegrass and Bahiagrass to irrigation and fertilizer practices. Dissertation presented to the University of Florida Graduate School, Gainesville, FL.

Park, D.M., J. L. Cisar, G. H. Snyder, J.E. Erickson, S.H. Daroub and K.E. Williams. 2005. Comparison of actual and predicted water budgets from two contrasting residential landscapes in south Florida. International Turfgrass Society Research Journal. 10:885-890.

Petrovic, A.M. 1990. The fate of nitrogenous fertilizers applied to turfgrass, J. Environ. Qual. 19:1-14.

Rieke, P.E., and B.G. Ellis. 1974. Effects of nitrogen fertilization on nitrate movement under turfgrasses. In E.C. Roberts (ed.) Proc. 2nd Int. Turfgrass Res. Conf. ASA, Madison, WI.19-21 June 1972. Blacksburg, V.A.

Saha, S.K., L. E. Trenholm, and J.B. Unruh. 2005. Effect of fertilizer source on water use of St. Augustinegrass and ornamental plants. Hortscience 40:2164-2166.

Salaiz, T.A., R.C. Shearman, T.P. Riordan, and E.J. Kinbacher. 1991. Creeping bentgrass cultivar water use and rooting responses. Crop Sci. 31:1331–1334.

Sartain, J. B. 2010. Comparative Influence of N Source on N Leaching and St. Augustinegrass Quality,Growth and N Uptake. Soil and Crop science Society of Florida. Vol 67.

SAS Institute. 1999. SAS Users guide. Carry, NC.

South Florida Water Management District. 2010. Available at https://my.sfwmd.gov/portal/page/portal/common/pdf/splash (verified 10 March 2010).

Council of the City of Sannibel. 2007. Ordinance No. 07-003. http://www.sanibelh2omatters.com/fertilizer/PDF/Fertilizer_Ordinance.pdf.

Shearman, R.C. 1986. Kentucky bluegrass cultivar evapotranspiration rates. HortScience 21:455–457.

Shearman, R.C., and J.B. Beard. 1973. Environmental and cultural preconditioning effects on the water use rate of Agrostis palustris Huds., cultivar Pencross. Crop Sci. 13:424–427.

Sheard, R. W., M. A. Haw, G. B. Johnson, and J. A. Ferguson. 1985. Mineral nutrition of bentgrass on sand rooting systems. In Proceedings of 5th International Turfgrass Research Conference, ed. F. Lemaire, 469–485.Avignon, France: INRA.

Starr, J.L., and H.C. DeRoo. 1981. The fate of nitrogen applied to turfgrass. Crop Sci. 21:531- 536.

Stewart, E.H., and W. C. Mills.1967. Effect of depth to water table and plant density on evapotranspiration rate in south Florida. T. ASAE. 10(6):746-747.

Snyder, G.H., B.J. Augustin, and J.M. Davidson. 1984. Moisture sensor-controlled irrigation for reducing N leaching in Bermudagrass turf. Agron. J. 76: 964-969.

Snyder, G. H., B. J. Augustin, and J. L. Cisar. 1989. Fertigation for stabilizing turfgrass nitrogen nutrition. p. 217-219 In H. Takatoh (ed.) Proc. 6th Int. Turfgrass Res. Conf. (Tokyo), Japanese Soc. Turfgrass Sci., Tokyo.

Spalding, R. F., and M. E. Exner. 1993. Occurrence of Nitrate in Groundwater- A Review. J. Environ. Qual. 22:392-402.

Titko, S., J.R. Street, and T.J. Logan. 1987. Volatilization of ammonia from granular and dissolved urea applied to turf. Agron. J. 79:535-540.

Trenholm, L. E., J.L. Cisar, and J.B. Unruh. 2000. St. Augustinegrass for Florida lawns. Univ. of Fla. Coop.Ext. Serv., ENH 5. Univ. of Florida, Gainesville, FL.

Trenholm, L.E., E.F. Gilman, G.W. Knox, and R.J. Black. 2002. Fertilization and irrigation needs for Florida lawns and landscapes. Univ. of Fla. Coop. Ext. Serv., ENH 860.Univ. of Florida, Gainesville, FL.

United States Environmental Protection Agency. 1976. Quality criteria for water. EPA-440/9-76-023. Office of Water Planning and Standards. USEPA., Washington, D.C.

Vernon, J. R., D. L. Cawthon, R. G. Dubes, and L. J. Klingbeil. 1993. Effects of clippings and fertilizer on warm-season turfgrasses. Texas J. Agri. Nat. Resour. 6:99-108.

Vitousek, P.M., J.D. Aber, R.W. Howarth, G.E. Likens, P.A.Matson, D.W. Schindler, W.H. Schlesinger, and D.G. Tilman. 1997. Human alteration of the global nitrogen cycle: Sources and consequences. Ecol. Appl. 7:737–750.

Wesely, R.W., R.C. Shearman, E.J. Kinbacher, and S.R. Lowry. 1987. Ammonia volatilization from foliar-applied urea on field-grown Kentucky bluegrass. HortScience 22:1278–1280.

Wolf, B. 1982. A comprehensive system of leaf analysis and its use for diagnosing crop nutrient status. Commun. Soil Sci. Plant Anal. 13:1035-1059.

Youngner, V.B., A.W. Marsh, R.A. Strohman, V.A. Gibeault, and S. Spaulding. 1981. Water use and quality of warm-season and cool-season turfgrass, p. 251–257. In R. W. Sheard (ed.) Proceedings of the 4th International Turfgrass Research Conference, Ontario Agricultural College, University of Guelph, Guelph, ON, Canada. 19–23 July.

Zazueta, F.S., A.G. Smajstria, and D.Z. Hamam. 1991. Estimation of evapotranspiration by the Penman method. Institute of Food and Agriculture Services. University of Florida. Florida Cooperative Extension Service. Circular 750. 6 p.

BIOGRAPHICAL SKETCH

Pauric C. McGroary was born in Letterkenny, Co. Donegal, Ireland, and grew up in Laghy, Co. Donegal, Ireland. In 1999 he graduated from St. Patrick's College with his leaving certification and began studies at University of Central Lancashire, Preston, England. In May 2004 he received a Bachelor of Science (Hons) in turfgrass science from University of Central Lancashire, Preston, England. Pauric continued his education at the University of Florida, Gainesville, FL were he joined the Entomology and Nematology Department and obtained a Master of Science degree in spring of 2007. In summer 2007, Pauric joined the graduate Soil and Water Department program at the University of Florida under the supervision of Dr. John Cisar in which he received his Doctor of Philosophy in August 2010.