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Nitrate Leaching and Turf Quality in Established 'Floratam' St. Augustinegrass and 'Empire' Zoysiagrass

Laurie E. Trenholm,* J. Bryan Unruh, and Jerry B. Sartain

The objectives of this research were to evaluate nitrate N (NO_3–N) leaching and turf response to nitrogen rate (NR) and irrigation regime (IR) in 'Floratam' St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze.) and 'Empire' zoysiagrass (*Zoysia japonica* Steud). The research was conducted in Citra, FL, from 2005 through 2007. Nitrogen (N) was applied at annual rates of 32, 64, 128, and 196 kg ha^{-1} in 2005, and at 49, 196, 343, or 490 kg ha^{-1} in 2006 and 2007. Irrigation treatments consisted of 1.3 cm applied twice weekly or 2.6 cm applied once weekly. In general, NO_3–N leaching was greater from zoysiagrass. In 2007, annual NO_3–N leached varied due to the interaction of NR, IR, and grass. There was little association between NR and increased NO_3–N leaching in St. Augustinegrass in any year. While St. Augustinegrass had no differences in NO_3–N leached within NR due to IR, there were some differences in NO_3–N leached from zoysiagrass at some N levels, with greater NO_3–N leached from the more frequent irrigation regime. Turf quality (TQ) was generally above an acceptable level in St. Augustinegrass at all but the lowest NRs and at all NRs in zoysiagrass with the exception of the spring fertilizer cycle (SFC) in 2007, when high NR treatments resulted in disease. Maintenance of a healthy turfgrass cover is an important strategy for reducing potential nutrient movement from fertilizer application. The current recommended rates for St. Augustinegrass provide good turf cover and health, and result in minimal NO_3–N leaching. Zoysiagrass N rates may need to be revised downward to reduce disease, improve turf cover, and reduce NO_3–N leaching.

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*Corresponding author (letr@ufl.edu).
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5585 Guilford Rd., Madison, WI 53711 USA

With increasing urbanization, there are concerns that urban turf fertilization may contribute to nonpoint-source pollution of ground and surface waters. To this end, there are some who support a cessation of or placement of severe restrictions on turf fertilization, although numerous research reports have clearly documented that many factors can influence N leaching from turf areas. These factors include N application rate (Brown et al., 1977; Shuman, 2001; Easton and Petrovic, 2004; Frank et al., 2006), N source (Geron et al., 1993; Easton and Petrovic, 2004), irrigation management (Starrett et al., 1995; Morton et al., 1998), maturity of the grass (Frank et al., 2006), and root architecture (Bowman et al., 1998; Bowman et al., 2002).

Frank et al. (2006) observed a range of 0 to 0.08 kg ha^{-1} labeled fertilizer N in leachate from established Kentucky bluegrass (*Poa pratensis* L.) that received urea N at 98 kg ha^{-1} annually compared with 0.01 to 0.73 kg N ha^{-1} leached from turf fertilized with 245 kg urea N ha^{-1} annually. The authors concluded that the 2 yr of research indicated that application of the low NR provided minimal potential for groundwater pollution, but that the high rate, particularly when applied as a single application, water soluble N source, may result in nitrate N (NO_3–N) levels in excess of the USEPA safe levels of 10 mg NO_3–N L^{-1}. The authors cited a need for subsequent years of research to verify these findings.

Morton et al. (1988) reported greatest annual flow-weighted NO_3–N concentration (4.02 mg L^{-1}) in a mixture of Kentucky bluegrass and red fescue (*Festuca rubra* L.) that received high N (244 kg ha^{-1} yr^{-1}) and excessive irrigation (3.75 cm wk^{-1}, regardless of rainfall). Annual N losses for this treatment totaled 32 kg inorganic-N ha^{-1}. The authors concluded that inorganic N leaching losses from appropriate home lawn care practices would not contribute to groundwater contamination, but that care should be used when fertilizing lawns in coastal watersheds.

Easton and Petrovic (2004) reported greater NO_3–N leaching losses from a mixture of Kentucky bluegrass and perennial ryegrass (*Lolium perenne* L.) treated with soluble urea than from an untreated

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L.E. Trenholm, Dep. of Environmental Horticulture, Univ. of Florida, PO Box 110670, Gainesville, FL 32611; J.B. Unruh, West Florida Research and Education Center, 4253 Experiment Dr., Jay, FL 32565; J.B. Sartain, Dep. of Soil and Water Sci., Univ. of Florida, PO Box 110510, Gainesville, FL 32611. Assigned to Associate Editor Pamela Rice.

Abbreviations: ESFC, early summer fertilizer cycle; ET, evapotranspiration; FFC, fall fertilizer cycle; HDPE, high-density polyethylene; IR, Irrigation regime; IR1, applied twice weekly; IR2, applied once weekly; LSFC, late summer fertilizer cycle; MDL, minimum detection limit; N, nitrogen; NO_3–N, nitrate N; NR, nitrogen rate; SFC, spring fertilizer cycle; TQ, turf quality.

control. Leaching losses were highest in the first year following turf establishment. The authors concluded that the potential for increased NO_3–N leaching is greatest during establishment, but the faster establishment time in turf that received fertilization during the first year reduced subsequent losses of N and phosphorus compared with unfertilized control plots.

Erickson et al. (2001) observed less NO_3–N leaching (4.1 kg N ha^{-1} annually) in the first year following establishment from sodded Floratam St. Augustinegrass than from a mixed-species landscape planting (48.3 kg N ha^{-1} annually). Reporting on long-term N leaching on this project (Erickson et al., 2008), authors observed that both turf and mixed-species landscape plantings leached <2% of the applied N as inorganic N over time. The decrease in leaching from the mixed-species landscape plantings was attributed to increased root mass over time and the cessation of fertilizer treatments applied to the mature mixed-species landscape plantings.

Bowman et al. (2002) observed a 92% reduction in NO_3–N leaching from St. Augustinegrass from a second treatment application as compared with the first treatment in a greenhouse study. Nitrogen was applied as ammonium nitrate at a rate of 50 kg N ha^{-1} on both treatment dates. The authors attributed the reduction in NO_3–N leaching following the second treatment application to development of a more extensive root system as the grasses matured, a larger microbial population to increase N immobilization, and less water percolation through the columns. Over the course of the study, lower cumulative levels of NO_3–N and a lower percentage of applied N leached from 'Raleigh' St. Augustinegrass than from five other species of warm-season grasses. Similarly, Bowman et al. (1998) attributed lower NO_3–N leaching from two creeping bentgrass (*Agrostis palustris* Huds.) genotypes to production of a deeper root system and they concluded that management strategies to enhance rooting may reduce NO_3–N leaching.

Current N fertilization recommendations for maintenance of St. Augustinegrass (Trenholm et al., 2011) and zoysiagrass (Unruh et al., 2011) in Florida include a range of rates from 98 to 294 kg N ha^{-1} annually, depending on geographical region of the state and aesthetic preference. Trenholm and Unruh (2007) observed best TQ and color from application of 200 or 350 kg N ha^{-1} to St. Augustinegrass. The authors noted that zoysiagrass could be maintained with 147 kg N ha^{-1} in central Florida (Trenholm and Unruh, 2009). Dunn et al. (1995) reported that a maximum rate of 98 kg N ha^{-1} annually was sufficient for 'Meyer' zoysiagrass maintenance but noted that more N may be necessary where sandy soils predominated.

Given that Florida currently has regulations at both state and local levels regarding fertilization of lawn grasses and due to a lack of NO_3–N leaching data on St. Augustinegrass and zoysiagrass, this research was undertaken as part of a larger project to obtain specific information for best management practices verification on NO_3–N leaching as a result of lawn grass fertilization. The objectives of this research were to evaluate total NO_3–N leaching and turf response from a wide range of NRs and from two different irrigation regimes in established Floratam St. Augustinegrass and 'Empire' zoysiagrass.

Materials and Methods

This research was conducted at the G.C. Horn Turfgrass Field Laboratory at the University of Florida Plant Science Research and Education Unit in Citra, FL. Soil type was a Tavares sand (Hyperthermic, uncoated Typic Quartzipsamments), with a pH of 6.8 and organic matter content of <4%.

Plots measured 4.0 m by 4.0 m. High-density polyethylene (HDPE) drainage lysimeters were installed in the center of each plot, with the top ∼10 cm below the soil surface. Lysimeters measured 57 cm diam. and 88 cm in height with a volume of 168 L. Lysimeters were assembled by placing HDPE cylinders into a single-piece, galvanized-steel base unit measuring 25.4 cm in height. A bulkhead fitting was inserted into the base of each unit, to which collection tubing (0.95 cm low-density polyethylene) was attached. The tubing was run underground to central aboveground collection portals. Lysimeters were installed by boring and removing soil in 15.2-cm sections to a depth of 107 cm. Lysimeters were placed in holes and 38 L of washed egg rock (1.9–6.4 cm) was placed in the bottom of each lysimeter. The gravel was covered with fitted nonwoven polyolefin cloth that was secured with a hoop of 1.3 cm HDPE tubing to reduce soil intrusion into the reservoir. Soil was replaced into the lysimeters as it had been removed from the soil profile. Soil was gently tamped with a tamping tool (17 kg and 858 cm^2) to approximate original soil bulk density. Empire zoysiagrass and Floratam St. Augustinegrass were sodded in late June 2005. Grasses received an initial fertilization with 24.5 kg N ha^{-1}on 24 June 2005. Irrigation was provided as needed to prevent wilt during establishment.

Nitrogen rate treatments were applied on 22 July and 20 Sept. 2005, 3 Apr., 6 June, 1 Aug., and 30 Sept. 2006, 2 Apr., 31 May, 8 Aug., and 3 Oct. 2007, as 46–0–0 urea. The urea was dissolved in water and applied through a backpack sprayer to uniformly cover each plot with a rate of 0.12 L m^{-2}. Treatments were irrigated in with 0.6 cm of water after application. In 2005, research was conducted over ∼4-mo growing period with annual application rates of 32, 64, 128, and 196 kg N ha^{-1}. In the subsequent 2 yr, research timing was representative of a typical north central Florida growing season of ∼7 mo. The rates for 2006 and 2007 were modified to reflect the longer growing season and obtain information on a higher range of N application, resulting in annual application rates of 49, 196, 343, or 490 kg N ha^{-1}, applied in ∼60-d intervals. These rates were applied at the request of the funding agency to provide information on NO_3–N fate if a homeowner were to greatly exceed recommended NRs. Results are reported as annual NO_3–N mass flux and for each 60-d fertilizer cycle between treatment applications. The fertilizer cycles are defined as spring fertilizer cycle (SFC), early summer fertilizer cycle (ESFC), late summer fertilizer cycle (LSFC), and fall fertilizer cycle (FFC). Irrigation treatments consisted of 1.3 cm applied twice weekly (IR1) or 2.6 cm applied once weekly (IR2). These rates were chosen to simulate typical watering restrictions enacted in parts of Florida. When rainfall met or exceeded these amounts, irrigation was suspended.

Turf was mowed weekly at a height of 8.9 cm with clippings returned. Pesticides were applied, as needed, based on visual identification of a pest. Chlorothalonil (2,4,5,6-tetrachloroisophthalonitrile) fungicide was applied to zoysiagrass plots on 15 May 2007, for control of Zoysia patch disease (*Rhizoctonia* spp.). Potassium (K) was applied three times annually throughout the growing season at 49 kg K ha^{-1} each application.

Leachate samples were collected twice weekly throughout the growing season, beginning the day after first treatment application. Samples were collected by applying a vacuum to the collection tubing and withdrawing percolate from the reservoir of the lysimeter until dry. To prevent a perched water table from forming, lysimeters were evacuated more than twice weekly if heavy rain events (>2.5 cm) occurred. The large surface area of the lysimeters minimized preferential flow within lysimeters. Volume was measured by collecting leachate into a graduated cylinder as lysimeters were emptied. Twenty-ml aliquots of the leachate were transferred to collection vials and placed on ice in the field and then frozen at 0°C until NO_3–N analysis was done. Nitrate concentration was measured using a continuous segmented flow analyzer (AutoAnalyzer 3, Seal Analytical) at the University of Florida Analytical Research Laboratory in Gainesville. Leachate volumes were also measured for each plot. Concentrations that were lower than the minimum detection limit (MDL) of 0.05 mg L^{-1} were corrected to the MDL value.

Turf quality (TQ) was assessed biweekly over the growing season on a scale of 1 to 9, where 1 = dead/brown turf and 9 = optimal healthy/green turf. A score of 6 was considered a minimally acceptable score for a home lawn. When disease damage occurred, TQ was assessed from the nondiseased portion of the plot. Spring greenup was assessed in 2006 and 2007, as a measurement of the percentage of the plot that had live green grass following winter dormancy.

Weather data were collected for the months in which research was conducted from an on-site weather network system (http://fawn.ifas.ufl.edu), which provides meteorological information in 15-min intervals.

Experimental design was a split–split plot design, where irrigation treatments were main plots and grasses were subplots. Nitrogen rates were randomized within grasses as sub–sub plots. There were four replications. Proc analysis of variance (SAS Institute, 2003) was used to analyze data and means were separated with the Waller Duncan *k*-ratio *t* test. Differences were determined at the 0.05 significance level. Due to differences in data among years, results are presented by year. Leachate data were found to be normally distributed and adjusted for outliers that exceeded plus or minus two standard deviations.

Results and Discussion

Precipitation

Actual monthly rainfall and historical averages for the growing seasons during the study period are shown in Fig. 1. Monthly rainfall for all years of the study was generally below historical averages; rainfall on an annual basis over the months comprising the study period was 19 and 17% below average for 2006 and 2007, respectively. However, there were months (August and October 2005, July 2006, and October 2007) when rainfall exceeded historical averages and some dates where daily rainfall events exceeded 25 mm. For example, in 2006, there were five daily rainfall events during LSFC that exceeded 25 mm.

Nitrate–Nitrogen Leaching

In 2005, NO_3–N mass flux did not differ in response to main effects or interactions (Table 1). In 2006, there were differences from the interaction of NR × grass in ESFC and FFC, and interaction of NR × IR in FFC, and for total annual flux (Table 1). In 2006, each fertilizer cycle and annual flux had differences in response to the main effect of grass, regardless of interactions (Table 2). In St. Augustinegrass, only LSFC had differences from NR, whereas in zoysiagrass, there was a trend toward

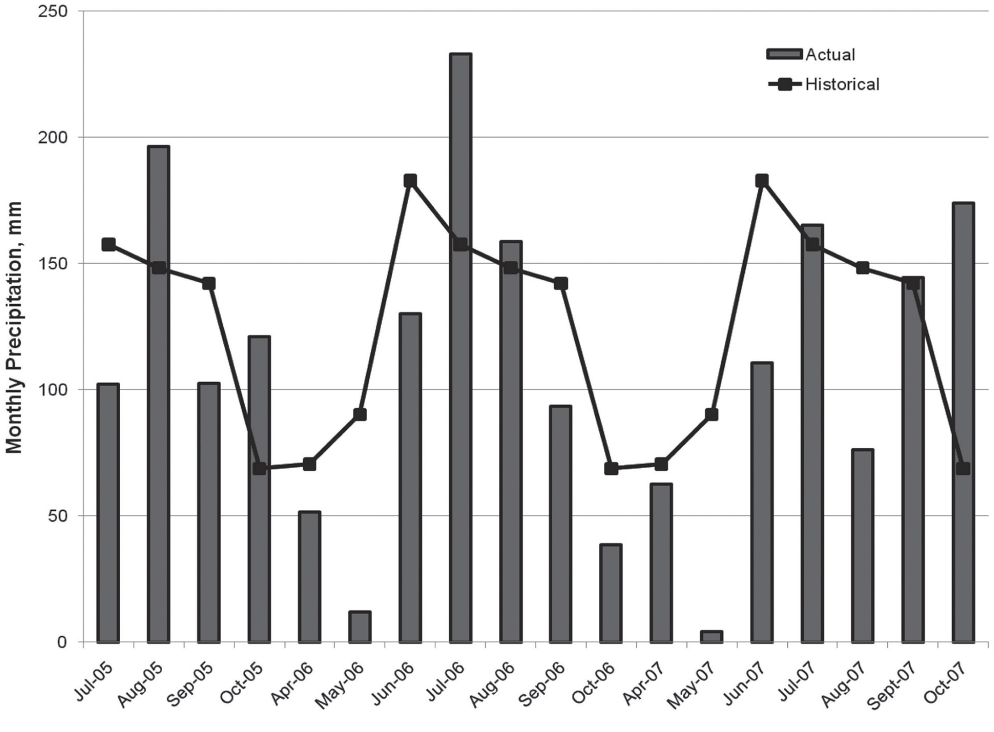

Fig. 1. Monthly precipitation for the months in which research was conducted over the 3-yr study period in Citra, FL.

Table 1. Analysis of variance for NO_3–N leached and turf quality in response to N rate (NR) and irrigation regime (IR) of established Floratam St. Augustinegrass and Empire zoysiagrass from 2005 to 2007, in Citra, FL.

Source of variation	Nitrate–N leached					Turf quality†				
	SFC‡	ESFC‡	LSFC‡	FFC‡	Annual	SFC	ESFC	LSFC	FFC	Average
2005										
NR	NA§	NA	NS¶	NS	NS	NA	NA	***	NS	**
Grass (G)	NA	NA	NS	NS	NS	NA	NA	***	NS	***
IR	NA	NA	NS	NS	NS	NA	NA	NS	NS	NS
NR × G	NA	NA	NS	NS	NS	NA	NA	**	***	***
NR × IR	NA	NA	NS	NS	NS	NA	NA	NS	NS	NS
G × IR	NA	NA	NS	NS	NS	NA	NA	NS	NS	NS
NR × G × IR	NA	NA	NS	NS	NS	NA	NA	NS	NS	NS
2006										
NR	NS	**	NS	*	**	***	***	***	***	***
G	**	***	***	*	***	NS	*	NS	NS	NS
IR	**	NS	NS	NS	NS	*	NS	NS	NS	*
NR × G	NS	*	NS	***	NS	***	***	***	***	***
NR × IR	NS	NS	NS	***	*	***	***	***	NS	***
G × IR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR × G × IR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2007										
NR	*	***	**	**	***	**	***	**	**	**
G	**	***	***	**	***	*	NS	NS	NS	NS
IR	NS	*	**	NS	*	NS	NS	NS	NS	NS
NR × G	***	***	*	*	***	***	***	***	***	***
NR × IR	***	NS	NS	NS	***	***	***	***	***	***
G × IR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NR × G × IR	NS	NS	*	NS	*	NS	NS	NS	NS	NS

* Significant at $P < 0.05$.

** Significant at $P \leq 0.01$.

*** Significant at $P \leq 0.001$.

† Turf quality based on a scale from 1–9, where 1 = dead/brown turf and 9 = optimal healthy/green turf. A score of 6 was considered a minimally acceptable score for a home lawn.

‡ SFC = spring fertilizer cycle; ESFC = early summer fertilizer cycle; LSFC = late summer fertilizer cycle; FFC = fall fertilizer cycle.

§ NA = not applicable. Research began with LSFC in 2005.

¶ NS = not significant at the 0.05 probability level.

Table 2. Nitrate–N leached from established Floratam St. Augustinegrass and Empire zoysiagrass in response to N rate in 2006 and 2007 in Citra, FL.

Annual N rate	Nitrate–N leached									
	St. Augustinegrass					Zoysiagrass				
	SFC†	ESFC†	LSFC†	FFC†	Annual	SFC	ESFC	LSFC	FFC	Annual
kg ha^{-1}	kg ha^{-1}									
					2006					
490	2.3a‡	1.6a	0.3a‡	1.1a	5.3a	7.3a	6.0a	10.1	5.7a	29.1a
343	1.9a	0.3a	0.1c	0.6a	2.9a	2.9a	1.4b	5.7	3.6b	13.7b
196	0.3a	0.3a	0.2b	0.2a	0.9a	6.7a	1.4b	7.6	1.0c	16.7b
49	0.3a	0.2a	0.2b	0.1	0.9a	6.5a	2.2ab	3.7	0.3d	12.7b
					2007					
490	0.2a	0.6c	0.3a	8.0a	9.1a	29.1a	75.8a	7.0a	12.5b	124.3a
343	0.3a	1.0a	0.2b	0.6b	2.1b	22.3b	40.3b	4.0ab	17.9a	84.5b
196	0.2a	0.8b	0.3b	1.6b	2.9b	6.4c	17.2c	0.6b	6.2bc	30.5c
49	0.1a	0.3d	0.2b	0.4b	1.1b	1.9d	2.4d	0.4b	1.0c	5.7d

† SFC = spring fertilizer cycle; ESFC = early summer fertilizer cycle; LSFC = late summer fertilizer cycle, FFC = fall fertilizer cycle.

‡ Values within a column by year followed by the same letter do not differ at $P = 0.05$.

higher NO_3–N leaching at the highest NR, particularly in FFC and for annual leaching. In FFC of 2006, NO_3–N mass flux increased under both IRs as NR increased; however, there were no differences in leaching within NR in response to IR (Table 3). Annual NO_3–N loading was not affected by NR under IR1, whereas NO_3–N loading increased with NR under IR2. As with FFC, IR did not affect NO_3–N within NR. Averaged over all other treatments, annual NO_3–N flux from St. Augustinegrass in 2006 was 1.4 kg N ha^{-1}, compared with 10.1 kg N ha^{-1} from zoysiagrass (data not shown).

There was an interaction of NR × grass × IR in LSFC and for annual NO_3–N mass flux in 2007 (Table 1). There were no differences in St. Augustinegrass in annual NO_3–N load in response to NR under IR1, whereas loading was greatest at the highest NR under IR2 (Table 4). There were no differences in NO_3–N loading within NR as influenced by IR. Zoysiagrass had greater annual NO_3–N mass flux under IR1 as NR increased and from the two highest NRs under IR2. Analyzed within NRs, greatest loading occurred from zoysiagrass under IR1 at both 196 and 490 kg N ha^{-1}, with no differences at 49 and 343 kg N ha^{-1} from IR. In 2007, zoysiagrass was more sensitive to NO_3–N loading under the less frequent but higher volume IR2 for annual leaching. Nitrate N losses from zoysiagrass decreased from 157.9 to 7.1 kg ha^{-1} NO_3–N under IR1, a decrease of 96% as NR decreased from 490 to 49 kg N ha^{-1}. The percentage decrease under IR2 was 95%, with means of 90.1 to 4.4 kg N ha^{-1} as NR decreased.

Table 3. Nitrate–N leached in response to the interaction of N rate and irrigation regime (IR) in established Floratam St. Augustinegrass and Empire zoysiagrass in fertilizer cycle 4 and for the growing season in 2006, in Citra, FL.

Annual N rate	Nitrate–N leached fall fertilizer cycle		
	IR†	IR2	*P* Value
	kg N ha^{-1}		
490	1.4a‡	5.4a	NS§
343	1.0b	3.1b	NS
196	0.7c	0.5c	NS
49	0.2d	0.3d	NS
		Annual Load	
490	19.3a	15.2a	NS
343	7.4b	9.2b	NS
196	14.0ab	3.6c	NS
49	11.8ab	1.8d	NS

† IR1 = irrigation regime 1, twice weekly at 1.3 cm; IR2 = irrigation regime 2, weekly at 2.6 cm.

‡ Values within a column for a cycle followed by the same letter do not differ at *P* = 0.05

§ NS = not significant within a row at *P* = 0.05.

Table 4. Annual nitrate–N leached in response to the interaction of grass, N rate, and irrigation regime (IR) in established Floratam St. Augustinegrass and Empire zoysiagrass in 2007, in Citra, FL.

Annual N rate	Nitrate–N leached		
	IR†	IR2	*P* Value
	kg N ha^{-1}		
		St. Augustinegrass	
490	7.2a	6.4a‡	NS§
343	1.4a	0.5b	NS
196	1.1a	4.1b	NS
49	1.1a	1.6b	NS
		Zoysiagrass	
490	157.9a	90.1a	¶
343	99.8b	69.1a	NS
196	50.3c	10.7b	¶
49	7.1d	4.4b	NS

† IR1 = irrigation twice weekly at 1.3 cm; IR2 = irrigation weekly at 2.6 cm.

‡ Values within a column for a grass followed by the same letter do not differ at *P* = 0.05.

§ NS = not significant.

¶ Significant at the 0.05 probability level within a row.

Irrigation at the rates and timings tested had limited effect on NO_3–N loading results, particularly in St. Augustinegrass, with some tendency for greater NO_3–N loss from zoysiagrass at the more frequent IR1 in 2007. The irrigation rates used in this study (2.54 cm wk^{-1}) were generally equivalent to or slightly less than evapotranspiration (ET). Consequently, percolate was not excessive and the percentage of applied N leached was generally $\leq$1% of the applied amount to St. Augustinegrass. It is likely that greater response to irrigation might be seen in both species if a wider range of scheduling and rates were tested, especially if irrigation rates significantly exceeded ET, thereby resulting in greater percolate volume.

Concentration of NO_3–N in percolate ranged from 0.05 to 0.86 mg L^{-1} from St. Augustinegrass for 2006 and 2007 (Table 5), well below the USEPA drinking water standards of 10 mg L^{-1}, regardless of N rate. Zoysiagrass concentrations were below EPA standards in 2006, ranging from 1.11 to 8.72 mg L^{-1}. The Zoysiagrass concentrations were 0.45 to 23.57 mg L^{-1} in 2007.

Correlation analysis of spring greenup with NO_3–N leached during SFC and ESFC for 2007 indicated that there were no significant associations in St. Augustinegrass between spring greenup and NO_3–N leached (Table 6). This was logical since greenup occurred rapidly in this species. Zoysiagrass had significant

Table 5. Means of NO_3–N concentration in percolate for 2006 and 2007 from established Floratam St. Augustinegrass and Empire Zoysiagrass in Citra, FL.

Annual N rate	Nitrate–N leached 2006		2007	
	St. Augustinegrass	Zoysiagrass	St. Augustinegrass	Zoysiagrass
kg ha^{-1}	mg L^{-1}			
490	0.86a†	0.80a	8.72a	23.57a
343	0.21a	0.17b	2.25b	10.83b
196	0.07a	0.21b	1.79b	3.55c
49	0.05a	0.08b	1.11b	0.45d

Analysis of variance	2006	2007
N rate (NR)	***	***
Grass (G)	***	***
Irrigation (IR)	NS‡	**
NR × G	**	***
NR × IR	NS	***
G × IR	NS	**
NR × G × IR	NS	**

** Significant at *P* ≤ 0.01

*** Significant at *P* ≤ 0.001

† Values within a column followed by the same letter do not differ at *P* = 0.05.

‡ NS = not significant within a row at *P* = 0.05.

Table 6. Correlation coefficients (*r*) and probability values (*P*) for NO_3–N leached vs. spring greenup in spring and early summer fertilizer cycles in 2007 for Floratam St. Augustinegrass and Empire Zoysiagrass in Citra, FL.

Nitrate–N leached	Percent spring greenup rating date				
	22 Mar.	12 Apr.	26 Apr.	17 May	31 May
			St. Augustinegrass		
Spring fertilizer cycle†	0.01 $P = 0.9735$	−0.02 $P = 0.9060$	−0.04 $P = 0.8224$	−0.04 $P = 0.8251$	−0.02 $P = 0.9273$
Early summer fertilizer cycle†	0.01 $P = 0.9471$	0.02 $P = 0.9131$	0.00 $P = 0.9798$	−0.02 $P = 0.9197$	−0.03 $P = 0.8746$
			Zoysiagrass		
Spring fertilizer cycle	−0.33 $P = 0.0653$	−0.65 $P = 0.0001$	−0.65 $P = 0.0001$	−0.78 $P = 0.0001$	−0.76 $P = 0.0001$
Early summer fertilizer cycle	−0.35 $P = 0.0494$	−0.58 $P = 0.0004$	−0.61 $P = 0.0002$	−0.72 $P = 0.0001$	−0.69 $P = 0.0001$

† SFC = spring fertilizer cycle; ESFC = early summer fertilizer cycle.

correlations with NO_3–N leached in both SFC and ESFC for each of the greenup rating dates in 2007. Zoysiagrass treated with the higher NRs had less live green tissue during the early growing season in 2007 due to increased presence of large patch disease (*Rhizoctonia solani* J.G. Kuhn), resulting in greater NO_3–N leached. Turf recovery began following fungicide treatment in mid-May. By LSFC, grass growth resumed with improved cover of plots and NO_3–N leaching levels were reduced. This illustrates the importance of a healthy turfgrass cover and cultural practices that sustain cover in reducing potential nutrient leaching.

There are varying reports of NO_3–N leaching from various turf species in response to increasing NR in the literature. For example, similar to results of St. Augustinegrass reported here, Easton and Petrovic (2004) found no differences in NO_3–N leaching due to NR in cool-season grasses in the second yr of a 2-yr study when N was applied from numerous sources at either 50 or 100 kg N ha^{-1}. In contrast, 'Tifdwarf' bermudagrass (*Cynodon dactylon* L. Pers × *C. transvaalensis* Burtt–Davy) putting greens lost 9.1 to 15.2 kg NO_3–N ha^{-1} as NRs increased from 24 to 98 kg applied N ha^{-1}, respectively, when N was applied as ammonium sulfate (Brown et al., 1977). Frank et al. (2006) reported higher total NO_3–N losses when N was applied at annual rates of 245 compared with 98 kg N ha^{-1} in Kentucky bluegrass.

Other reports have contrasted NO_3–N leaching among turf species and with other plant species used in the landscape. Erickson et al. (2001) reported annual inorganic-N loss of 4.1 kg ha^{-1} from St. Augustinegrass as compared with 48.3 kg ha^{-1} from a mixed-species landscape in the first year of the study. The authors concluded that St. Augustinegrass was a more effective filter for leachate reduction than a mixed landscape planting. Lowest NO_3–N leaching was reported from St. Augustinegrass when compared with other warm-season turfgrass species (Bowman et al., 2002). The authors attributed the reduced loading in St. Augustinegrass to the significantly greater root length density in this species at soil depths >30 cm.

Increased NO_3–N leaching from zoysiagrass in response to NR and irrigation is consistent with numerous reports of NO_3–N leaching in many turf species. Bowman et al. (2002) reported that 'Meyer' zoysiagrass was the least efficient of six warm-season turfgrasses at reducing N leaching and that St. Augustinegrass was the most efficient. In a mixed stand of Kentucky bluegrass and red fescue, Morton et al. (1988) reported higher inorganic-N concentrations in percolate when irrigation was applied at a rate of 3.75 cm wk^{-1} (excessive irrigation) than when applied on a tensiometer-based irrigation schedule. Similarly, Snyder et al. (1984) reported less NO_3–N leached from bermudagrass that received sensor-based irrigation treatments than from plots receiving a daily irrigation regime. Brown et al. (1977) reported that NO_3–N losses were minimized when irrigation was matched with ET. Starrett et al. (1995) reported 30 times greater N in leachate from columns that received heavy irrigation following fertilization treatment compared with a lighter, more frequent irrigation following fertilizer treatment.

Turf Quality

Turf quality scores varied in all years from the interaction of NR × grass and NR × IR in 2006 and 2007 (Table 2). In St. Augustinegrass, the three highest NRs provided acceptable TQ in all fertilizer cycles, with the exception of turf that received ≤196 kg N ha^{-1} in SFC of 2006 (Table 7). The lowest NR provided adequate TQ only in ESFC of 2007.

Table 7. Average turf quality of established Floratam St. Augustinegrass and Empire Zoysiagrass in response to N rate by fertilizer cycle n 2006 and 2007, in Citra, FL.

Annual N rate	Turf quality†									
	St. Augustinegrass					Zoysiagrass				
	SFC‡	ESFC‡	LSFC‡	FFC‡	Average	SFC‡	ESFC	LSFC	FFC	Average
kg ha^{-1}	1–9									
					2006					
490	6.7a§	9.0a	7.8a	7.3a	7.2a	6.5a	8.7a	7.2a	5.8d	6.7b
343	6.5b	8.5b	7.4b	6.9b	6.9b	6.4b	8.6b	7.1b	6.3b	6.8a
196	5.8c	7.4c	6.6c	6.2c	6.1c	6.4c	8.5c	7.0c	6.4a	6.6c
49	4.6d	5.4d	5.0d	4.1d	4.5d	6.2d	8.0d	6.8d	5.9c	6.3d
					2007					
490	7.4a	9.8a	7.7a	7.3a	7.5a	4.9b	8.0a	7.0b	6.7a	6.2a
343	7.0b	9.5b	7.6b	7.1b	7.3b	5.5ab	8.4a	6.9c	6.4a	6.4a
196	6.2c	8.5c	6.8c	6.5c	6.6c	6.0a	8.6a	7.1a	6.5a	6.6a
49	4.2d	6.6d	5.4d	4.8d	4.9d	6.4a	8.6a	6.8d	6.4a	6.6a

† Turf quality was based on a scale of 1 to 9, where 1 = dead/brown turf and 9 = optimal healthy/green turf. A score of 6 was considered minimally acceptable for a home lawn.

‡ SFC = spring fertilizer cycle, ESFC = early summer fertilizer cycle, LSFC = late summer fertilizer cycle, FFC = fall fertilizer cycle.

§ Values within a column followed by the same letter do not differ at $P = 0.05$.

Zoysiagrass quality followed a different trend, with acceptable TQ at all NRs in 2006, except for the lowest and highest rates in FFC of 2006 and at the two highest rates in SFC of 2007 (Table 7). In SFC of 2007, plots receiving the highest NRs had greater incidence of large patch disease as previously discussed. Plots at the lower NRs were not as severely affected. All plots maintained good TQ following fungicide application for the remainder of the year. Zoysiagrass had few differences in TQ in response to NR in 2007, other than in LSFC, when highest quality was reported from application of N at 196 kg ha^{-1}, with lower TQ in plots receiving higher NRs. Previous research (Trenholm and Unruh 2009) also indicates that zoysiagrass can maintain sufficient TQ at lower NRs.

Conclusions

These results suggest that actively growing, healthy turfgrass mitigates NO_3–N leaching from fertilization events. Maintenance of a healthy turfgrass cover is critical to reducing NO_3–N leaching and therefore all turf management practices can be important best management strategies for reducing NO_3–N leaching. St. Augustinegrass leaching had little association with NR, even when N was applied at the very high rates imposed here. Over the duration of the study, St. Augustinegrass quality was above acceptable N rates of $\geq$196 kg ha^{-1} yr^{-1}. Zoysiagrass showed greater potential for increased NO_3–N leaching when turfgrass was damaged from disease and cover was lacking. However, as demonstrated in previous research (Dunn et al., 1995; Trenholm and Unruh, 2009), as well as the current research, zoysiagrass requirements for N are less than those of St. Augustinegrass. Acceptable TQ scores were maintained at $\leq$196 kg N ha^{-1} annually, at which rates of potential NO_3–N losses were reduced. These results suggest that N recommendations for maintenance of Empire zoysiagrass in central and north Florida may need to be revised downward, since quality can be maintained at lower N levels, disease incidence is reduced, and potential leaching could be minimized. While it is outside the scope of this research to determine if impairment of ground or surface waters will result from application of the currently recommended N rates, this research indicates that these rates will produce minimal NO_3–N leaching, particularly from St. Augustinegrass. Further research is needed to determine the impacts of runoff from lawn fertilizers.

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