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RESEARCH

Nitrogen Required for Acceptable Centipedegrass Quality, Color, Growth Rate, and Nitrate Leaching

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ABSTRACT

In northern Florida, nitrogen (N) application recommendations for centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.] range from 49 to 98 kg ha^{-1} yr^{-1}. The objective of this study was to determine the minimum amount of N necessary to produce acceptable quality centipedegrass while also measuring the influence of irrigation rate on color, growth rate, and NO_3–N leaching. Nitrogen was applied at rates of 18, 36, 74, and 147 kg ha^{-1} yr^{-1} split evenly into three application cycles in 2006 and again in 2007 to common centipedegrass. Acceptable turf quality and color was produced by N applied at 18 kg ha^{-1} yr^{-1} during all cycles. Turf color and quality increased with increasing N rate (NR) for yearly average and many of the cycles. Nitrate N leaching was equivalent for NRs 18 and 147 kg ha^{-1} yr^{-1}. However, when NRs increased from 18 to 36 and 74 kg ha^{-1} yr^{-1}, annual NO_3–N leaching was reduced by ~50%. Current recommended NRs may be more than is necessary to produce acceptable quality centipedegrass; however, the rates do not pose an increased risk to NO_3–N leaching.

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Abbreviations: EFC, early-fall cycle; LSC, late-spring cycle; NR, nitrogen rate; SC, summer cycle.

Centipedegrass is a low-input turfgrass commonly used in Florida that requires less maintenance and less N than many other warm-season turfgrass species (Unruh et al., 2011). Currently, University of Florida recommendations for N fertilization of centipedegrass in northern Florida range from 49 to 98 kg ha^{-1} yr^{-1} (Florida Department of Environmental Protection, 2010). However, these NRs have generally been based on observational data rather than published research conducted in the environmental conditions of Florida.

Several studies have determined the N requirement of centipedegrass under various environmental conditions. Johnson and Carrow (1992) measured quality of centipedegrass established in Georgia as influenced by NRs of 25, 50, 200, and 300 kg ha^{-1} yr^{-1} and observed acceptable turf was produced by an NR of 25 kg ha^{-1} yr^{-1}. Additionally, the authors observed reduced turf quality as NRs increased above 50 kg ha^{-1} yr^{-1}. Similarly, Toler et al. (2007) reported acceptable centipedegrass quality was maintained using 24.4 kg N ha^{-1} yr^{-1} and further noted acceptable turf was observed in plots receiving no N in 2 out of 3 yr in South Carolina. Centipedegrass maintained without N applications may exhibit acceptable quality but unacceptable color (Carrow et al., 1988).

Numerous studies have reported that irrigation rate and frequency influence turf quality and N leaching. Snyder et al. (1984)

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investigated N leaching from bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) maintained under sensor-based irrigation vs. daily irrigation. The authors reported that peak N concentrations under sensor-based irrigation were reduced by ~50% when compared with daily irrigation. Irrigation regimes in the Snyder et al. (1984) study resulted in different quantities of applied water. However, Barton and Colmer (2006) proposed that applying the same quantity of water by reducing the application rate and increasing the application frequency may reduce N leaching by preventing preferential flow. Shaddox et al. (2016b) investigated this concept on St. Augustinegrass [*Stenotaphrum secundatum* (Walter) Kuntze] and reported that irrigation regime did not influence N leaching. The authors hypothesized that because the quantity of applied water resulted in similar leachate volumes leached N was similar among irrigation regimes. University of Florida recommends that the quantity of water applied should not vary seasonally, though the frequency should change according to the season (Trenholm et al., 2013). However, this irrigation recommendation has not been investigated on centipedegrass.

The environmental fate of applied nutrients is a concern because of Florida's sandy soils and high rainfall. Although numerous studies have determined that N applied to healthy turfgrass in Florida does not readily leach (Erickson et al., 2008; Shaddox et al., 2016a; Telenko et al., 2015), nitrate leaching studies on centipedegrass are limited. Additionally, many homeowners desire a turf quality that generally occurs only in the presence of applied N. Thus, N fertilization encompassing rates likely applied by homeowners should be examined to identify those rates that may lead to an increased potential for N loading of water bodies. Bowman et al. (2002) investigated N leaching from six warm-season turfgrass species and reported centipedegrass leached less than or as much NO_3–N than 'Meyer' zoysiagrass (*Zoysia japonica* Steud.), 'Emerald' zoysiagrass [*Z. japonica* × *Z. pacifica* (Goudsw.)], 'Tifway' hybrid bermudagrass [*C. dactylon* Pers. (L.) × *C. transvaalensis* Burtt-Davy], and common bermudagrass (*C. dactylon*). Only 'Raleigh' St. Augustinegrass [*S. secundatum* (Walter) Kuntze] leached less NO_3–N than centipedegrass. Telenko et al. (2015) investigated the influence of various N sources on NO_3–N leaching from St. Augustinegrass and centipedegrass and reported −0.8% of applied N leached from centipedegrass when N was applied as urea at 196 kg ha^{-1} yr^{-1}.

Florida has diverse environmental conditions, and it is crucial that recommended NRs be properly investigated within those conditions to determine if acceptable turfgrass can be achieved. Additionally, information regarding the influence of NRs on NO_3–N leaching from centipedegrass maintained in Florida's environment is limited. Thus, the objectives of this study were to determine the amount of N required to maintain acceptable quality centipedegrass while concurrently determining the influence of N and irrigation rate on color, growth rate, and NO_3–N leaching.

MATERIALS AND METHODS

This study was conducted from 2006 through 2007 at University of Florida's West Florida Research and Education Center in Jay (30°46′ N, 87°08′ W). The soil type was Fuquay loamy sand (loamy, kaolinitic, thermic Arenic Plinthic Kandiudults) with a pH of 6.2. A split-plot design was used with irrigation in 15- by 12-m main plots and NRs in 6- by 3-m subplots.

High-density polyethylene lysimeters were installed in the center of each subplot with the top rim of the lysimeter ~10 cm below the soil surface. Lysimeters measured 57 cm in diam. and 88 cm in height with a volume of 168 L. Lysimeters were placed on top of 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 a collection tube (0.95 cm low-density polyethylene) was attached. Connected tubing ran underground to a central, aboveground collection terminal. A leaching bed of washed round river rock (1.9–4.4 cm) covered with nonwoven polyolefin cloth secured with an internal interference fitted hoop of 1.3 cm high density polyethylene tubing was placed in the bottom of each lysimeter to minimize soil intrusion into the collection reservoir. The void space in the river rock layer resulted in a 20-L reservoir in which leachate could remain for vacuum extraction. Once lowered into bore holes, original soil horizons were recreated in 15-cm sections within the lysimeter, each carefully prepared by dropping a tamping tool (17 kg and 858 cm^2) from a consistent height to approximate original soil bulk density. Any settling of lysimeters was corrected prior to plot preparation for sodding using a laser-transit-controlled wheeled box blade. Common centipedegrass sod grown on a Norfolk fine sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults) (Woerner Turf, Elberta, Al.) was planted on 1 May 2005.

Treatments included four NRs and two irrigation regimes. Nitrogen was applied using solubilized urea applied through a CO_2 backpack sprayer to uniformly cover each subplot with a rate of 0.12 L m^{-2}. Nitrogen treatments were 18, 36, 74, and 147 kg ha^{-1} yr^{-1} and were applied on 14 Apr., 14 June, 11 Aug. 2006; and 16 Apr., 14 June, and 14 Aug. 2007. Irrigation treatments consisted of 13 mm applied twice weekly or 26 mm applied once weekly. Irrigation regimes were designed to determine if irrigation frequency influenced the measured variables, and irrigation regimes were consistent with common watering practices in northern Florida (Dukes, 2014). Irrigation was not suspended for rainfall events. Irrigation was supplied by four Toro Super 800 rotary irrigation heads (The Toro Company) per plot arranged in a square layout with four,90° arcs.

Centipedegrass was cut at a height of 5 cm prior to the urea application. Subsequent tissue harvests were collected weekly, placed in a forced-air oven at 70°C for 48 h and weighed. Phosphorus and K were applied in the spring of 2006 and 2007 as granular applications of triple superphosphate at 12 kg P ha^{-1} and potassium chloride at 49 kg K ha^{-1}.

Leachate samples were collected twice weekly by removing all leachate by vacuum extraction for volume determination and acquiring a 20-mL subsample for NO_3–N plus NO_2–N analysis from each lysimeter. In the Florida panhandle, most

Table 1. Type III tests for fixed effects of NO_3–N leached, quality, color, and growth rate in response to year (Y), N rate (NR), and irrigation (I) on common centipedegrass from 2006 to 2007 in Jay, FL.

Source of variation	Nitrate-N leached†				Quality†				Color†				Growth rate†			
	LSC	SC	EFC	A	LSC	SC	EFC	AVG	LSC	SC	EFC	AVG	LSC	SC	EFC	AVG
Year (Y)	NS‡	NS	*	NS	*	*	*	*	NS	**	**	**	***	***	**	**
N rate (NR)	*	NS	*	*	***	***	***	***	***	***	***	***	***	***	***	***
Irrigation (I)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × NR	NS	NS	NS	NS	NS	**	*	NS	NS	***	***	***	***	***	NS	NS
2006																
NR linear	NS	NS	NS	NS	**	***	***	***	**	***	***	***	***	***	***	***
NR quadratic	**	NS	**	*	NS	NS	NS	NS	NS	NS	NS	NS	***	NS	**	**
NR cubic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2007																
NR linear	NS	NS	NS	NS	***	***	***	***	***	***	***	***	ND§	ND	***	***
NR quadratic	NS	NS	NS	NS	***	***	NS	***	***	***	NS	***	ND	ND	**	**
NR cubic	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS	ND	ND	NS	NS
Y × I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I × NR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × I × NR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

† LSC, late-spring cycle; SC, summer cycle; EFC, early-fall cycle; A, annual cumulative; AVG, average of cycles.

‡ NS, nonsignificant.

§ ND, nondetectable.

turf managers apply nutrients on 60-d cycles beginning in the spring. Therefore, collection cycles began when treatments were applied and continued for ~60 d. Upon completion of a 60-d cycle, the next cycle began without interruption. Collection cycles are defined as late-spring cycle (LSC) (mid-April–mid-June), summer cycle (SC) (mid-June–mid-August), and early-fall cycle (EFC) (mid-August–mid-October). Because nutrients were not applied during the winter and turfgrass was dormant, leachate collection was halted from mid-October through mid-April. Nitrate concentration was measured using a continuous segmented flow analyzer (AutoAnalyzer 3, Seal Analytical) at the University of Florida Analytical Research Laboratory, Gainesville, FL, using the USEPA method 353.2 (USEPA, 1983). Concentrations that were lower than the minimum detection limit of 0.05 mg L^{-1} were assigned the minimum detection limit value. Leached NO_3–N was analyzed as mass flux. Nitrate N leached as mass flux was determined by multiplying the effluent concentration by the effluent volume.

Turf quality and color ratings were taken according to the criteria determined by Krans and Morris (2007). Turf quality and turf color were recorded once every 2 wk during the growing season on a scale of 1 to 9, where quality of 1 indicated dead or brown turf and quality of 9 indicated optimal healthy and green turf and where a color value of 1 indicated light green and color of 9 indicated dark green. Turf quality and color ratings $\geq$6.0 were considered acceptable.

Weather data were collected during the duration of the research from a weather station located 350 m from the research location. This station was part of a regional weather network system (http://fawn.ifas.ufl.edu), which provided meteorological information in 15-min intervals. Each interval between 0000 h on the first day of the month and 2359 h on the last day of the month were used to determine monthly averages.

Statistical analysis was performed on data pooled by collection cycle. Both main and subplots were arranged in a randomized complete block design, with each main and subplot treatment being replicated four times. Type III tests were adjusted for a split-plot design. Model residuals were analyzed for normality both graphically and numerically with the Shapiro–Wilk *W*-test. Data were also checked graphically for homogeneity of variance. These tests determined NO_3–N leaching and turf growth rate data were non-normal, while turf quality and color data were normally distributed. Thus, NO_3–N leaching and growth rate data were transformed logarithmically, and analysis of variance was conducted on the transformed data. Procedure GLIMMIX of SAS version 9.4 (SAS Institute, 2012) was used to analyze data and mean separation was conducted using the Tukey–Kramer at $P < 0.05$. Regression of NR and turf quality was performed using SigmaPlot version 12.5 (Systat Software Inc., 2013). Significant year (Y) × NR interactions were detected in LSC and EFC, thus regression of NR and turf quality was conducted with years.

RESULTS

Nitrogen Leaching

Nitrate N leached was influenced by year and NR, whereas turf quality, color, and growth rate were regularly influenced by the Y × NR interaction (Table 1). Irrigation had no influence on any of the response variables examined in this study and, thus, irrigation results are not reported.

Nitrogen rates of 36 and 74 kg ha^{-1} resulted in ~50% less NO_3–N leaching than the 18 kg ha^{-1} rate during LSC, EFC, and annual total (Table 2). Nitrate N leaching resulting from the application of 147 kg ha^{-1} was equal

Table 2. Nitrate-N leached in response to main effects N rate and year from centipedegrass from 2006 to 2007 in Jay, FL.

Fixed effect	NO$_3$–N leached†			
	LSC	SC	EFC	Annual
N rate (kg ha^{-1} yr^{-1})	ln(kg ha^{-1})			
18	−1.48 (0.30)a‡	−1.18 (0.39)a	−1.62 (0.24)a	−0.27 (0.93)a
36	−2.51 (0.14)b	−1.94 (0.25)a	−2.31 (0.17)b	−1.07 (0.57)b
74	−2.49 (0.12)b	−1.72 (0.21)a	−2.34 (0.13)b	−0.97 (0.46)b
147	−1.86 (0.36)ab	−1.38 (0.32)a	−1.62 (0.23)a	−0.43 (0.91)ab
Year				
2006	−2.00 (0.20)a	−1.91 (0.20)a	−2.32 (0.14)b	−0.44 (0.54)a
2007	−2.17 (0.26)a	−1.20 (0.39)a	−1.63 (0.25)a	−0.93 (0.90)a

† LSC, late-spring cycle; SC, summer cycle; EFC, early-fall cycle.

‡ Within a columns, treatment means followed by the same letter are not different according to Tukey–Kramer at $P < 0.05$.

Table 3. Centipedegrass quality, color and growth rate in response to N rate in 2006 and 2007 in Jay, FL.

Fixed effect	Quality†				Color†				Growth rate			
	LSC‡	SC‡	EFC‡	AVG‡	LSC	SC	EFC	AVG	LSC	SC	EFC	AVG
N rate (kg ha^{-1} yr^{-1})	1-to-9 scale								ln(g m^{-2} d^{-1})			
2006												
18	6.6b§	7.0c	7.2c	6.9c	6.8b	7.2c	7.3c	7.1c	−2.44 (0.17)b	−1.51 (0.30)b	−0.98 (0.44)c	−1.46 (0.31)bc
36	6.7b	7.2bc	7.4c	7.1bc	6.8b	7.3bc	7.6c	7.2bc	−2.82 (0.06)b	−1.46 (0.24)b	−1.07 (0.34)c	−1.54 (0.22)c
74	7.0b	7.7b	8.0b	7.6b	7.1ab	7.7b	8.1b	7.6b	−2.46 (0.09)b	−1.02 (0.38)b	−0.48 (0.63)b	−1.03 (0.36)b
147	7.8a	8.4a	8.6a	8.3a	7.8a	8.3a	8.6a	8.2a	−1.47 (0.23)a	−0.42 (0.67)a	0.19 (1.22)a	−0.35 (0.71)a
2007												
18	6.0c	6.1c	6.6 d	6.3 d	6.2c	6.0c	6.5 d	6.3 d	0.00 (0.00)¶	0.00 (0.00)	−2.14 (0.21)b	−3.24 (0.07)b
36	6.1c	6.4c	7.0c	6.5c	6.4bc	6.2c	6.8c	6.5c	0.00 (0.00)	0.00 (0.00)	−2.37 (0.09)b	−3.47 (0.03)b
74	6.5b	7.3b	7.9b	7.2b	6.7b	7.0b	7.8b	7.2b	0.00 (0.00)	0.00 (0.00)	−1.95 (0.15)b	−3.05 (0.05)b
147	7.5a	8.3a	8.5a	8.1a	7.7a	8.2a	8.5a	8.1a	0.00 (0.00)	0.00 (0.00)	−1.05 (0.36)a	−2.14 (0.12)a

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

‡ LSC, late-spring cycle; SC, summer cycle; EFC, early-fall cycle; AVG, average.

§ Within columns, treatment means followed by the same letter are not different according to Tukey-Kramer at $P < 0.05$.

¶ Values without variability were not analyzed.

to NO$_3$–N leaching from the 18 kg ha^{-1} rate during each cycle and annual cumulative. No differences in NO$_3$–N leaching were observed among NRs during the SC. Leaching differences among years was significant only during EFC with approximately twofold greater leaching observed in 2007 than in 2006.

Turf Quality, Color, and Growth Rate

Centipedegrass quality and color remained above acceptable levels under each NR during each cycle in 2006 and 2007 (Table 3). Increasing applied N from 18 to 36 kg ha^{-1} did not influence centipedegrass quality during 2006. However, both the 74 and 147 kg ha^{-1} rates resulted in an increase in turf quality during SC, EFC, and the annual average. Increasing N applied from 18 to 36 kg ha^{-1} did not increase centipedegrass color during 2006, but increasing N from 18 to 74 kg ha^{-1} did increase centipedegrass color during SC, EFC, and the annual average in 2006. Compared with the 18 kg N ha^{-1} rate, the 147 kg N ha^{-1} rate increased color by at least one unit during each cycle and the annual average in 2006. Growth rate was increased using 147 kg N ha^{-1} compared with 18 kg N ha^{-1} during each 2006 cycle, whereas growth rate was not increased by either 36 or 74 kg N ha^{-1} during most cycles and annual average.

In 2007, each NR resulted in acceptable turf quality ratings (Table 3). During LSC and SC, similar turf quality ratings resulted from 18 and 36 kg N ha^{-1}. Annual turf quality and color ratings increased with each increase in N rate (Table 3). Centipedegrass growth rate during LSC and SC were 0.0 g m^{-2} d^{-1} and, thus, no differences among NRs were observed. Centipedegrass growth rates during EFC of 2007 were equal among the 18, 36, and 74 kg N ha^{-1} rates. The 147 kg N ha^{-1} resulted in a 0.15 g m^{-2} d^{-1} greater growth rate than the 18 kg N ha^{-1} during EFC. The average annual growth rate produced by the 147 kg N ha^{-1} rate was 0.05 g m^{-2} d^{-1} greater than the 18 kg N ha^{-1} rate.

As a result of the Y × NR interaction, the relationship of NR and turf quality was determined within years (Fig. 1). Regression analysis of NR effects in LSC and SC were performed using 32 (four ratings events × two irrigation rates × four replicates) and 24 observations (three rating events × two irrigation rates × four replicates) for

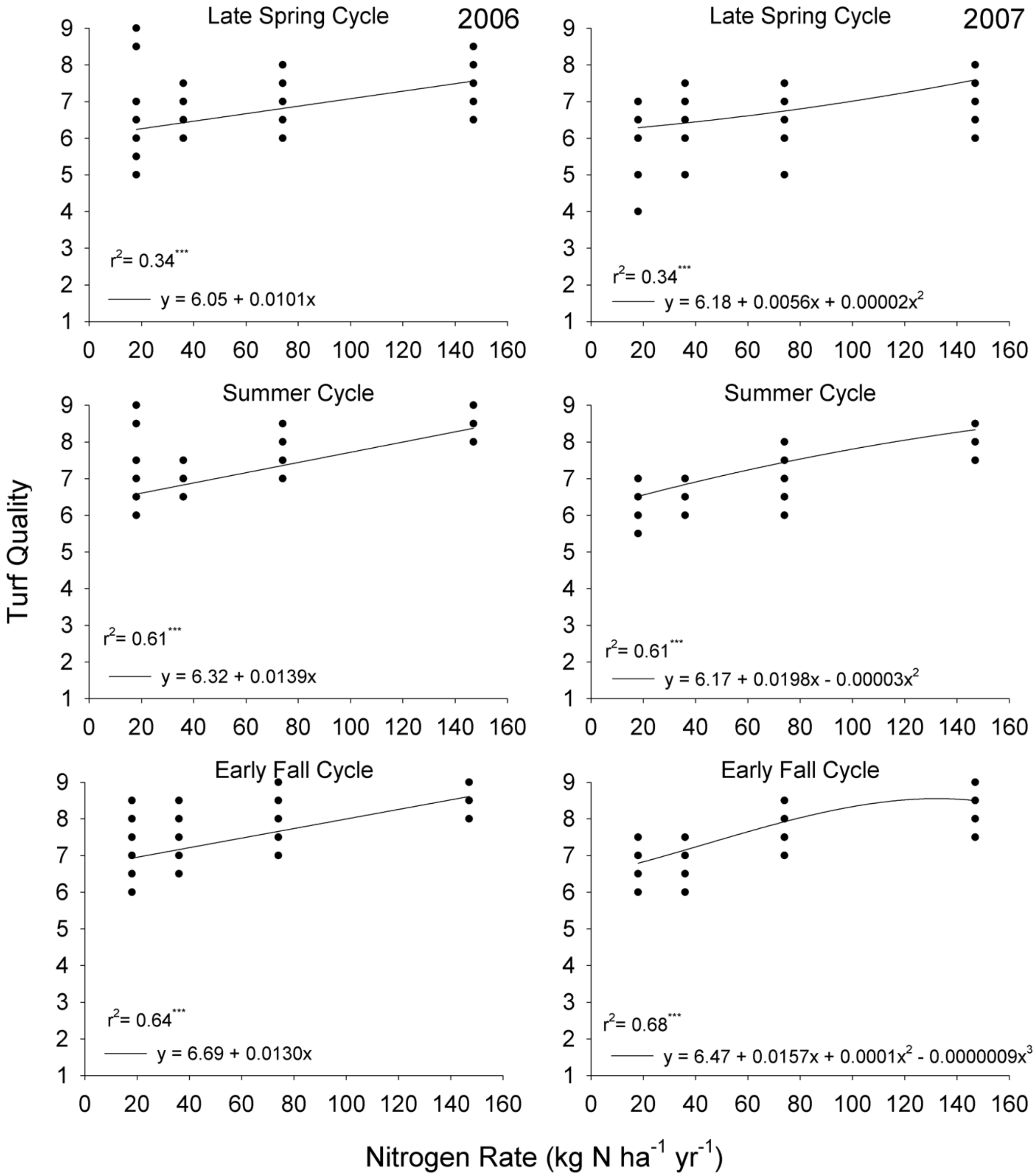

Fig. 1. Relationship between N rate and common centipedegrass quality during the late-spring cycle, summer cycle, and early-fall cycle during 2006 and 2007 in Jay, FL. In late-spring cycles and summer cycles of 2006 and 2007, data include 32 observations (4 rating events × 2 irrigation rates × 4 replicates) and 24 observations (3 rating events × 2 irrigation rates × 4 replicates), respectively. In the early-fall cycle of 2006 and 2007, data include 24 observations (3 rating events × 2 irrigation rates × 4 replicates) and 48 observations (6 rating events × 2 irrigation rates × 4 replicates), respectively. Asterisks (***) indicate regression significance at $P < 0.001$.

the years 2006 and 2007, respectively. In the EFCs of 2006 and 2007, data include 24 observations (three rating events × two irrigation rates × four replicates) and 48 observations (six rating events × two irrigation rates × four replicates), respectively. Each cycle in 2006 resulted in a significant linear relationship (Table 1), whereas in 2007, the LSC, SC, and EFC resulted in quadratic, linear, and cubic relationships, respectively. In LSC of 2006 and 2007, NR and turf quality were poorly correlated (r = 0.58). The correlation increased in each year as the study progressed into the SC and EFC (r = 0.78 and 0.80, respectively). Each regression model was found to be significant at $P < 0.001$.

Lower air and soil temperatures and decreased precipitation was observed in 2007 than in 2006 during most months from January through June (Table 4). Notably, soil temperatures in April and June were 2.1 and 1.2°C, respectively, lower in 2007 than in 2006. Additionally,

Table 4. Average monthly air temperature, soil temperature, evapotranspiration, and cumulative monthly precipitation from 2006, 2007, and 10-yr historical average in Jay, FL.

	Air temperature			Soil temperature			Precipitation			Evapotranspiration		
	2006	2007	10-yr average	2006	2007	10-yr average	2006	2007	10-yr average	2006	2007	10-yr average
	°C						cm					
January	13.2	10.5	9.7	14.2	13.3	12.1	10.9	13.1	12.8	0.15	0.13	0.12
February	11.0	10.2	10.7	13.0	11.7	12.6	11.1	8.4	12.2	0.18	0.18	0.18
March	15.6	15.9	15.0	16.7	16.4	16.2	4.6	3.0	10.5	0.28	0.28	0.25
April	20.9	17.7	19.0	21.4	19.3	20.4	12.1	7.6	15.0	0.38	0.33	0.34
May	23.5	22.8	22.8	24.3	24.0	24.4	5.6	4.4	11.3	0.43	0.41	0.40
June	26.7	26.1	26.1	27.5	26.3	27.5	8.1	2.8	12.8	0.46	0.43	0.44
July	27.0	26.6	26.2	28.4	28.0	28.3	11.9	14.9	19.7	0.38	0.43	0.42
August	27.1	27.8	26.1	28.9	28.5	28.5	17.6	7.3	13.6	0.41	0.41	0.38
September	23.4	25.0	24.0	26.3	26.4	26.6	4.2	13.2	10.4	0.33	0.36	0.33
October	18.7	20.4	18.9	22.0	22.5	22.0	11.1	18.6	10.8	0.23	0.23	0.24
November	13.1	14.2	13.5	15.8	17.0	16.7	6.4	13.2	8.6	0.15	0.15	0.15
December	11.7	13.2	11.7	13.9	15.3	14.2	8.0	12.5	14.7	0.13	0.13	0.12

precipitation from February through June of 2007 was 15 cm lower (40% reduction) than in 2006.

DISCUSSION

Irrigation

Irrigation regime did not influence N leaching, turf quality, turf color, or growth rate. Previous studies have reported that irrigation does influence N leaching and turfgrass quality (Ashley et al., 1965; Barton and Colmer, 2006); however, most studies have investigated irrigation rates that provide differing amounts water (Dobbs et al., 2014; Snyder et al., 1984). The present study investigated irrigation regimes that provided the same amount of water split into either one or two applications per week. Thus, we postulate that because the total amount of applied water and precipitation was equivalent among treatments, equivalent responses were observed. Other researchers have reported similar results when similar amounts of water are applied (Erickson et al., 2010; Shaddox et al., 2016b; Trenholm et al., 2012).

Nitrate Leaching

Because of financial constraints, analysis was limited to measuring the NO_3–N concentration of leachate only. In arable soils, rapid oxidation of N species is commonly observed, and NO_3–N has been the dominant N species found in many turfgrass leaching studies (Bowman et al., 2002; Erickson et al., 2010). Nevertheless, because urea was applied and only NO_3–N was measured, it is possible that the total N leached was greater than the amount measure. However, this would have no influence on the relative values among years, NRs, and turfgrass.

A 50% reduction in NO_3–N leaching was observed when NRs were increased from 18 to 36 and 74 kg ha^{-1} yr^{-1}. This observation is contrary to many previous reports. Wu et al. (2010) investigated NO_3–N leaching from ammonium nitrate applied to tall fescue [*Schedonorus phoenix* (Schreb.) Dumort.] at rates of 195, 293, and 390 kg ha^{-1} yr^{-1} and reported NO_3–N leaching increased dramatically as NRs increased. Similarly, Easton and Petrovic (2004) applied urea at 200 kg N ha^{-1} yr^{-1} using rates of 50 and 100 kg N ha^{-1} to a blend of Kentucky bluegrass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.). The authors observed 82 and 186 kg ha^{-1} NO_3–N leached in year one and 18 and 22 kg ha^{-1} NO_3–N leached in year two from the 50 and 100 kg N ha^{-1} treatments, respectively. Other researchers have reported similar increases in NO_3–N leaching associated with increasing NRs (Barton et al., 2009; Exner et al., 1991). However, the lowest investigated annual NR has generally been 49 kg ha^{-1} (Fetter et al., 2012; Petrovic, 1990), which is nearly threefold higher than our lowest NR. Some research indicates reduced NO_3–N leaching when N is applied at low rates. Morton et al. (1988) monitored N leaching losses from Kentucky bluegrass subjected to 0, 97, and 244 kg ha^{-1} yr^{-1} and reported N leaching was reduced during two of their four collection periods by 8 and 16% when NRs were increased from 0 to 97 kg ha^{-1} yr^{-1}. Fetter et al. (2012) applied soluble N to perennial ryegrass at 0 and 48 kg ha^{-1} yr^{-1} and reported a 60% reduction in NO_3–N leaching during the second year of their study when NRs were increased from 0 to 48 kg ha^{-1} yr^{-1}. While results from Fetter et al. (2012) and Morton et al. (1988) were deemed to be statistically insignificant, they do imply N leaching may decrease as NRs increase under certain conditions. We postulate these conditions may include low NRs applied to low-input turfgrass.

When N was applied at 147 kg ha^{-1} yr^{-1}, NO_3–N leaching was equivalent to that produced by the 18 kg ha^{-1} yr^{-1} treatment during each cycle and annual cumulative. Currently, the University of Florida recommended NRs for centipedegrass in northern Florida are 49 to 98 kg

ha^{-1} yr^{-1}. Because the range of NRs investigated include both the 49 and 98 kg ha^{-1} yr^{-1}, these results indicate the current recommended N application ranges do not pose an increased risk to NO_3–N leaching.

Quality

Low NRs have resulted in acceptable centipedegrass by other investigators. Carrow et al. (1988) investigated NRs on centipedegrass and reported acceptable quality was observed at NRs ranging from 0 to 39 kg ha^{-1}. Toler et al. (2007) applied varying NRs to centipedegrass in South Carolina and reported acceptable quality was produced by applying N at 24.4 kg ha^{-1} yr^{-1}.

Current University of Florida minimum recommended NR is 49 kg ha^{-1} yr^{-1}. Some previous research supports our findings (Carrow et al., 1988; Toler et al., 2007), while other studies indicate less N is necessary to achieve acceptable quality centipedegrass (Johnson and Carrow, 1988). Protracted periods of no N addition have been shown to eventually produce unacceptable centipedegrass (Telenko et al., 2015). Establishing a turfgrass and then depriving that turfgrass of the minimum necessary nutrition may lead to poor turf quality and potentially increase the risk of non-point-source nutrient additions to surface or ground water. This topic may warrant further investigation. However, under our experimental conditions, N applied at 18 kg ha^{-1} yr^{-1} was the minimum NR resulting in acceptable centipedegrass. While additional N up to 147 kg ha^{-1} yr^{-1} would increase turf quality without increasing NO_3–N leaching, additional N would not be necessary unless greater than acceptable turf quality levels were desired. Although measurements of atmospheric and mineralized N were beyond our intended scope of research, it is likely that a portion of N assimilated by centipedegrass originated from these sources. In northeastern Florida, atmospheric inorganic N deposition may approach 3.0 kg ha^{-1} yr^{-1} (National Atmospheric Deposition Program, 2015). Natural N source additions from atmospheric and mineralized N may significantly contribute to the observed acceptable turf quality and color.

The cause of the poor correlation of NR and turf quality observed in LSC of 2006 and 2007 is unknown. Generally, NR and turf quality are well correlated if measured during active growth or on an annual basis (Shaddox et al., 2016b; Trenholm and Unruh, 2007). Because the LSC was from mid-April through mid-June, we postulate that the turfgrass had not yet achieved optimum growth because of reduced temperature and moisture compared with the SC or LSC (Table 4). Prior studies have reported turfgrass physiology may change in response to changes in light or temperature (Munshaw et al., 2006; Okeyo et al., 2011). These results underscore the importance of including the time of year into nutrient recommendations. It is possible that the responses observed during the SC and LSC were a result of N accumulation from the prior applications. Further investigations regarding the causality of the poor correlation in the LSC would be valuable.

Color

Centipedegrass color response was similar to turf quality with acceptable color observed at each NR during each cycle and annual average. Toler et al. (2007) also reported acceptable color from NRs ranging from 0 to 195 kg ha^{-1} yr^{-1}. Johnson et al. (1988) published similar results with NRs ranging from 0 to 200 kg ha^{-1} yr^{-1}. The minimum acceptable color rating maintained during the SC of 2007 by the 18 kg N ha^{-1} yr^{-1} treatment clearly indicates that acceptable color can be achieved under similar environmental conditions. However, if environmental conditions such as lower temperature or limited rainfall impart an additional stress on the turfgrass, it is likely that acceptable turf color would not be achieved by the 18 kg N ha^{-1} yr^{-1} treatment. Turfgrass managers should be aware of this potential concern before implementing the 18 kg N ha^{-1} yr^{-1} rate in environments different from those used in our study.

Growth Rate

Increasing NR to 74 and 147 kg ha^{-1} yr^{-1} resulted in increased growth rate during most cycles. This finding agrees with those reported by other researchers on other warm-season turfgrass (McGroary et al., 2009; Trenholm and Unruh, 2007). During the LSC and SC of 2007, centipedegrass produced no growth as a result of a slow transition out of dormancy. While turf quality and color were acceptable, we postulate that the lower air temperature, soil temperature, and precipitation from January through June of 2007 contributed to a reduction in turf growth. Previous researchers have documented the influence of low temperature and the plant's ability to tolerate these temperatures on turf growth (Dunn et al., 1999; Malyshev and Henry, 2012) and the transition out of dormancy (Baldwin et al., 2009).

CONCLUSIONS

Nitrate N leaching, turf quality, turf color, and growth rate of centipedegrass were not affected by irrigation when equivalent amounts of water are applied via one or two weekly applications to replace water loss via evapotranspiration. Results indicate the current University of Florida N recommendation range for centipedegrass in northern Florida do not pose an increased risk to NO_3–N leaching. However, results also indicate that the lowest recommended rate (49 kg N ha^{-1} yr^{-1}) may provide more N than is necessary to produce acceptable centipedegrass. A rate of 18 kg N ha^{-1} yr^{-1} may result in acceptable quality centipedegrass during the entire season and produce little risk to NO_3–N leaching.

Conflict of Interest

The authors declare that there is no conflict of interest.

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