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RESEARCH

Nitrate Leaching from Soluble Nitrogen Applied to 'Floratam' St. Augustinegrass and Common Centipedegrass during Dormancy

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ABSTRACT

Fertilizer bans in Florida prevent turf managers from applying nitrogen (N) fertilizers during periods of active turf growth and may encourage fertilization in fall and winter. Nutrient applications during fall or winter may pose an increased risk to nitrate N (NO_3–N) leaching. A 3-yr field lysimeter study was conducted in Jay, FL, to determine the effect of N rates on NO_3–N leaching from 'Floratam' St. Augustinegrass (SA) [*Stenotaphrum secundatum* (Walter) Kuntze] and common centipedegrass (CE) [*Eremochloa ophiuroides* (Munro) Hack.] during turfgrass dormancy. Treatments consisted of urea applied as a foliar spray every 45 d beginning in October at rates of 0.0, 6.0, 12.5, 24.0, or 49.0 kg N ha^{-1}. Leachate was collected weekly and analyzed for NO_3–N. Elevated NO_3–N levels were observed for 105 d after initiation (DAI). No differences in NO_3–N leached were detected among N rates until the late winter cycle of 2008 when rainfall exceeded historic levels by 268 mm. The 49.0 kg N ha^{-1} treatment resulted in more NO_3–N leached than untreated turf during 2008, with 12.5 and 1.3 kg NO_3–N ha^{-1} leached, respectively. These findings suggest that N rates $\leq$24.0 kg ha^{-1} applied to dormant or semidormant warm-season turf do not pose an increased threat of NO_3–N leaching even when rainfall is excessive. Soluble N rates >24.0 kg ha^{-1} should be avoided during dormancy when excessive rainfall is imminent. The benefits, if any, need to be investigated further before fertilization of dormant warm-season turf is recommended.

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Abbreviations: CE, centipedegrass; DAI, days after initiation; df, degree of freedom; FC, fall cycle; *G*, grass; HDPE, high-density polyethylene; LFC, late fall cycle; LSC, late summer cycle; LWC, late winter cycle; MDL, minimum detection limit; NR, N rate; SA, St. Augustinegrass; WC, winter cycle; *Y*, year.

Spring and summer fertilization is a widely recommended practice for warm-season turfgrasses. When recommended timing and application rates are followed, applications of N during the spring and summer pose little threat to ground water because of assimilation of applied N (Erickson et al., 2008; Guertal and Howe, 2012; Hochmuth et al., 2012; Trenholm et al., 2012). Despite the overwhelming amount of research to support spring and summer turf fertilization, numerous county and local governments continue to enact fertilizer bans in certain areas of Florida. These bans (i.e., summer blackout) prevent applications of N and P fertilizers between 1 June and 30 September (Sarasota County, Ord. No. 2007-062; Town of Longboat Key, Ord. No. 2008-07; City of North Port, Ord. No. 2007-45), which coincides with what is often the rainy season in peninsular Florida. It is supposed that increased N leaching occurs during the rainy season. If turf managers or homeowners who work or reside in these ban areas choose to fertilize their turf, they are now restricted to fertilizing in the fall, winter, or early spring. Since most turf in north and central Florida is in a dormant or semidormant condition during these seasons, N applications during the fall and winter may actually pose an increased threat to groundwater

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Soil and turf N dynamics have been shown to be influenced by season, and thus, NO_3–N leaching could also be influenced by N application dates. Miltner et al. (2001) investigated repeated monthly applications of N at 49 kg N ha^{-1} to perennial ryegrass (*Lolium perenne* L.) in Washington and reported inorganic soil N concentration was higher in the fall and spring than in the summer months. Guillard and Kopp (2004) applied various N sources at 147 kg N ha^{-1} yr^{-1} to a mixture of Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass, and creeping red fescue [*Festuca rubra* L. subsp. *arenaria* (Osbeck) F. Aresch] and reported that NO_3–N leaching losses occurred primarily in the late fall through early spring. Geron et al. (1993) reported higher NO_3–N concentrations in leachate from Kentucky bluegrass receiving N fertilization in November compared with plots receiving no November N application.

Generally, applications of soluble N increase the risk of NO_3–N loading of groundwater compared with controlled-release N. Telenko et al. (2015) investigated NO_3–N leaching from SA treated with N sources applied at 49 kg N ha^{-1} and reported applications of urea, polymer-coated urea, and biosolids resulted in NO_3–N leaching of 15.6, 4.6, and 5.0 kg ha^{-1}. Other researchers have also reported that soluble N sources leach greater N than controlled-release N sources (Bauer et al., 2012; Guillard and Kopp, 2004; Wu et al., 2010).

While the above-mentioned research provides information regarding the potential threat of NO_3–N leaching in the fall, most research has been conducted on cool-season turf, which exhibits different growth patterns than warm-season turf throughout the fall and winter months. The risk of NO_3–N leaching from warm-season turf during the fall and winter could be excessive and is less well understood than NO_3–N leaching during periods of active growth. We are unaware of any study that compared NO_3–N leaching at various N rates applied during the fall and winter to warm-season turfgrass. Therefore, the objectives of this research were to determine the influence of N rate and grass on NO_3–N leaching from soluble N applied to Floratam SA and common CE during the winter months in north Florida.

MATERIALS AND METHODS

The study was conducted from 2006 until 2009 at University of Florida's West Florida Research and Education Center in Jay Florida (30°46′ N, 87°08′ W). The soil series was Fuquay loamy sand (loamy, kaolinitic, thermic Arenic Plinthic Kandiudults), with a pH of 6.2. A split-plot experiment was used with turfgrass species in 15- by 12-m main plots and N rates in 6- by 3-m subplots. Both main and subplots were arranged in a randomized complete block design with four replications.

High-density polyethylene (HDPE) lysimeters were installed in the center of each subplot, with the top rim of the lysimeter approximately 10 cm below the soil surface. Lysimeters measured 57-cm diam. and 88 cm in height resulting in a volume of 224 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 tubing (0.95 cm low-density polyethylene) was attached. Connected tubing ran underground to a central, aboveground collection station. A leaching bed of washed, round river rock (1.9 to 4.4 cm) covered with nonwoven polyolefin cloth secured with an internal interference fitted hoop of 1.3-cm HDPE tubing was placed in the bottom of each lysimeter to minimize soil intrusion into the collection reservoir (20 L). Leachate volumes never exceeded 20 L. Once lowered into bore holes, original soil horizons were reestablished in 15-cm depth sections within the lysimeter, each carefully prepared by dropping a tamping tool (17 kg and 858 cm^2) from a consistent height to approximate the original soil bulk density (1.53 g cm^{-3}). Any settling of lysimeters was corrected before plot preparation for sodding using a laser-transit-controlled, wheeled-box blade. Plots were sodded with common CE and Floratam SA on 25 Sep. 2006.

Treatments included five rates of N using solubilized urea applied through a CO_2 backpack sprayer to uniformly cover each subplot at a rate of 0.12 L m^{-2}. Nitrogen rate treatments were 0.0, 6.0, 12.5, 24.0, and 49 kg ha^{-1}. Treatments were applied on 23 Oct. and 6 Dec. 2006; 18 Jan., 5 Mar., 31 Aug., 16 Oct. and 30 Nov. 2007; 15 Jan., 29 Feb., 28 Aug., 13 Oct., and 1 Dec. 2008; and 15 Jan. and 2 Mar. 2009. Grass was irrigated with 0.6 cm of water after treatment applications. Turf was mown at a height of 5 cm for CE and 7.5 cm for SA. Clippings were allowed to remain on plots.

Leachate samples were collected by removing all leachate by vacuum extraction for volume determination, and a 20-mL subsample was stored in polyethylene scintillation vials (Fisher Scientific) for NO_3–N + NO_2–N analysis. Leachate subsamples were acidified to 2.0 pH, stored at 4°C, and analyzed within 28 d. Leachate was collected twice weekly during 2006 and 2007 collection cycles. Collection cycles are defined as late summer cycle (LSC; 1 Sep.–15 Oct.), fall cycle (FC; 16 Oct.–30 Nov.), late fall cycle (LFC; 1 Dec.–15 Jan.), winter cycle (WC; 16 Jan.–29 Feb.), and late winter cycle (LWC; 1 Mar.–15 Apr.). At the request of the funding agency, all subsequent leachate collections occurred weekly. Collection cycles began when fertilizer treatments were applied and continued for approximately 45 d. 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 (MDL) of 0.05 mg L^{-1} were corrected to the MDL value.

Weather data were collected during the duration of the research from an on-site weather network system (http://fawn.ifas.ufl.edu), which provided meteorological information in 15-min intervals. Irrigation was supplied by four Rain Bird Super 7005 (Rain Bird Corp.) rotary irrigation heads set to deliver 0.5 mm of water per minute. Irrigation heads were installed at the corner of each main plot, used 90° arc tips, and ran every 3 to 4 d with four irrigation events between 0200 and 0630 h with run times being adjusted to provide approximately 80% of previous week's evapotranspiration.

Table 1. Analysis of variance and orthogonal contrasts of nitrate N leached in response to year (*Y*) grass (*G*) and N rate (NR) from St. Augustinegrass (SA) and centipedegrass (CE) from 2006 to 2009 in Jay, FL.

Source of variation	df	Nitrate N leached† LSC	FC	LFC	WC	LWC	Annual
		ln (kg ha^{-1})					
Year (*Y*)	2	NS‡	***	***	***	***	***
2006–2007 vs. others	1	NA§	***	***	***	NS	***
2007–2008 vs. 2008–2009	1	NA	**	*	*	**	*
Grass (*G*), St. Augustinegrass (SA) vs. centipedegrass (CE)	1	NS	NS	NS	NS	**	NS
Nitrogen rate (NR), kg ha^{-1}	4	NS	NS	NS	*	***	***
0.0 vs. others	1	NS	NS	NS	NS	NS	NS
6.0 + 12.5 vs. 24.0 + 49.0	1	NS	NS	NS	**	***	***
6.0 vs. 12.5	1	NS	NS	NS	NS	NS	NS
24.0 vs. 49.0	1	NS	NS	NS	**	***	***
Y × *G*	2	NS	NS	NS	NS	*	NS
2006–2007 vs. others × SA vs. CE	1	NS	NS	NS	NS	***	NS
2006–2007 vs. 2007–2008 × SA vs. CE	1	NS	NS	NS	NS	NS	NS
Y × NR	8	NS	NS	NS	NS	***	***
2006–2007 vs. 2007–2008 + 2008–2009 × 0.0 vs. Others	1	NS	NS	NS	NS	NS	NS
2006–2007 vs. 2007–2008 + 2008–2009 × 6.0 + 12.5 vs. 24.0 + 49.0	1	NS	NS	NS	NS	*	*
2006–2007 vs. 2007–2008 + 2008–2009 × 6.0 vs. 12.5	1	NS	NS	NS	NS	NS	NS
2006–2007 vs. 2007–2008 + 2008–2009 × 24.0 vs. 49.0	1	NS	NS	NS	NS	**	*
2007–2008 vs. 2008–2009 × 0.0 vs. Others	1	NS	NS	NS	NS	NS	NS
2007–2008 vs. 2008–2009 × 6.0 + 12.5 vs. 24.0 + 49.0	1	NS	NS	NS	NS	**	***
2007–2008 vs. 2008–2009 × 6.0 vs. 12.5	1	NS	NS	NS	NS	NS	NS
2007–2008 vs. 2008–2009 × 24.0 vs. 49.0	1	NS	NS	NS	NS	**	***
G × NR	4	NS	NS	NS	NS	NS	NS
SA vs. CE × 0.0 vs. Others	1	NS	NS	NS	NS	NS	NS
SA vs. CE × 6.0 + 12.5 vs. 24.0 + 49.0	1	NS	NS	NS	NS	NS	NS
SA vs. CE × 6.0 vs. 12.5	1	NS	NS	NS	NS	NS	NS
SA vs. CE × 24.0 vs. 49.0	1	NS	NS	NS	NS	*	*
Y × *G* × NR	8	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 summer cycle; FC, fall cycle; LFC, late fall cycle; WC, winter cycle; LWC, late winter cycle. LSC, FC, LFC, WC, and LWC were 1 Sep. to 15 Oct., 16 Oct. to 30 Nov., 1 Dec. to 15 Jan., 16 Jan. to 29 Feb., and 1 Mar. to 15 Apr., respectively.

‡ NS, nonsignificant.

§ NA, not applicable. Research began in the FC of 2006–2007.

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 data were non-normal. Thus, data were transformed via natural logarithm and analysis of variance was conducted on the transformed data, which satisfied assumptions of normality and homogeneity of variance. Procedure GLM in SAS version 9.4 (SAS Institute, 2013) was used to analyze logarithmic transformed data. Main effects of year (*Y*), grass (*G*), and N rate (NR) were analyzed as fixed effects. Single degree-of-freedom (df) orthogonal contrasts were constructed for each main effect and each two-way interaction. The orthogonal contrasts for the effect of year on leaching were partitioned into two single df contrasts: (i) compare the establishment year (2006–2007) with the mean for years following establishment (2007–2008 and 2008–2009) and (ii) compare between the two individual years following establishment (2007–2008 vs. 2008–2009). The effects of the five NR on leaching were partitioned according to four orthogonal linear contrasts: (i) compare unfertilized treatments (0 kg N ha^{-1}) with the mean of fertilized treatments (6.0, 12.5, 24.0, and 49.0 kg N ha^{-1}), (ii) compare the mean of low NR (6.0 and 12.5 kg N ha^{-1}) vs. the mean of high NR (24.0 and 49.0 kg N ha^{-1}), (iii) compare within the low NR (6.0 vs. 12.5 kg N ha^{-1}), and (iv) compare within the high NR (24.0 vs. 49.0 kg N ha^{-1}). Each single-df main-effect contrast was multiplied by other main effect, single-df contrasts to partition *Y* × *G*, *Y* × NR and *G* × NR interactions. The interaction *Y* × *G* × NR was nonsignificant. Dunnett's least significant differences values at the 0.05 level are reported for comparison between N rate treatments and the untreated control.

RESULTS

A significant year effect was observed during each applicable cycle (Table 1). Greater leaching was observed during the establishment year of 2006 to 2007 than 2007 to 2008 and 2008 to 2009 during each cycle (Table 1, 2). The greatest amount of NO_3–N leaching during any cycle was

Table 2. Nitrate N leached during late summer cycle, fall cycle, and late fall cycle as influenced by the main effects of year, grass, and N rate in Jay, FL. Values in parentheses represent backtransformed values.

	Nitrate N leached†					
	LSC	FC	LFC	WC	LWC	Annual
	ln (kg ha^{-1})					
Year						
2006–2007	NA‡	2.45 (13.36)	1.66 (6.53)	0.11 (1.77)	–1.41 (0.61)	2.99 (22.28)
2007–2008	–2.31 (0.14)	–1.62 (0.21)	–1.47 (0.24)	–1.02 (0.51)	–1.74 (0.25)	0.13 (1.37)
2008–2009	–2.79 (0.08)	–2.11 (0.14)	–1.00 (0.60)	–1.67 (0.32)	–0.33 (2.49)	0.51 (3.65)
$LSD_{0.05}$	NS§	0.35	0.39	0.69	0.83	0.43
Grass						
St. Augustinegrass	–2.48 (0.11)	–0.50 (4.42)	–0.41 (2.09)	–1.26 (0.60)	–1.76 (0.83)	1.03 (8.03)
Centipedegrass	–2.62 (0.11)	–0.35 (4.72)	–0.13 (2.83)	–0.46 (1.14)	–0.56 (1.40)	1.39 (10.17)
$LSD_{0.05}$	NS	NS	NS	NS	0.80	NS
N Rate (kg ha^{-1})						
0.0	–2.21 (0.12)	–0.50 (3.87)	–0.36 (2.15)	–0.95 (0.83)	–1.22 (0.48)	1.06 (7.42)
6.0	–2.94 (0.11)	–0.48 (4.75)	–0.31 (2.84)	–1.08 (0.66)	–1.62 (0.34)	0.99 (8.69)
12.5	–2.41 (0.11)	–0.45 (3.87)	–0.36 (1.94)	–0.99 (0.77)	–1.39 (0.51)	1.02 (7.19)
24.0	–2.89 (0.09)	–0.47 (5.13)	–0.32 (2.44)	–0.88 (0.73)	–1.40 (0.48)	1.11 (8.85)
49.0	–2.33 (0.11)	–0.21 (5.23)	0.00 (2.92)	–0.38 (1.34)	–0.18 (3.77)	1.87 (13.36)
$LSD_{0.05}$	NS	NS	NS	0.52	0.58	0.39

† LSC, late summer cycle; FC, fall cycle; LFC, late fall cycle; WC, winter cycle; LWC, late winter cycle. LSC, FC, LFC, WC and LWC were 1 Sep. to 15 Oct., 16 Oct. to 30 Nov., 1 Dec. to 15 Jan., 16 Jan. to 29 Feb., and 1 Mar. to 15 Apr., respectively.

‡ NA, not applicable. Research began in the FC of 2006–2007.

§ NS, nonsignificant.

approximately 13 kg ha^{-1} observed during the FC of 2006 to 2007. The contrast 2007 to 2008 vs. 2008 to 2009 indicates NO_3–N leaching differed among individual years following the establishment year, but the differences were not consistent among cycles. Greater leaching was observed in 2007 to 2008 than 2008 to 2009 during FC and WC, while more leaching was observed in 2008 to 2009 during LFC, LWC, and annual cumulative (Table 2).

Nitrate N leaching was similar among grasses except during the LWC (Table 1, 2). During LWC, NO_3–N leaching through CE exceeded NO_3–N leaching from SA by 0.57 kg ha^{-1}, or 41%. Nitrate N leaching differed as a result of the $Y \times G$ interaction during the LWC (Table 1). Centipedegrass led to greater NO_3–N leaching than SA only during the establishment year (2006–2007). During 2006 to 2007, NO_3–N leaching from CE and SA was 1.04 and 0.18 kg N ha^{-1}, respectively.

Nitrogen rate had no influence on total NO_3–N leaching during LSC, FC, or LFC but did influence NO_3–N leaching during WC, LWC, and annual cumulative (Table 1, 2). Nitrate N leaching from fertilized vs. unfertilized turfgrass and from the 6.0 kg N ha^{-1} rate vs. the 12.5 kg N ha^{-1} rate was similar during each cycle. The two highest N rates (24.0 and 49.0 kg ha^{-1}) resulted in greater NO_3–N leaching than the two lowest rates (6.0 and 12.5 kg ha^{-1}) during the WC, LWC, and annual cumulative. Similarly, the 49 kg N ha^{-1} rate led to greater NO_3–N leaching than the 24.0 kg N ha^{-1} rate during the WC, LWC, and annual cumulative. Nitrate N leaching from unfertilized turfgrass was similar to each N rate treatment except the 49 kg N ha^{-1} treatment during the WC, LWC, and annual cumulative (Table 2).

Nitrate N leaching was influenced by the $Y \times$ NR interaction during the LWC and annual cumulative (Table 1). According to the main effects for year and corresponding single-df contrasts (Table 1, 2), (i) no difference in NO_3–N leaching during the LWC was observed between the establishment year (2006–2007) and the mean for years following establishment (2007–2008 and 2008–2009) and (ii) year 2008 to 2009 promoted greater leaching during the LWC than year 2007 to 2008. However, year affected NO_3–N leaching during the LWC through its interaction with NR. During the LWC, no difference in NO_3–N leaching between the establishment year (2006–2007) and post-establishment years (2007–2008 and 2008–2009) was observed when N rates of $\leq$24 kg N ha^{-1} were applied (Table 3), which is consistent with the main effects for year. Conversely, 49 kg N ha^{-1} promoted greater NO_3–N leaching during the postestablishment period (2007–2008 and 2008–2009) than the establishment year, which is a major departure from the main effects for year. Additionally, 49 kg N ha^{-1} promoted greater nitrate leaching in year 2008 to 2009 than 2007 to 2008 during the LWC, which is consistent with the main effects for year on leaching (Table 2, 3). Departures from the main effects for year caused by interactions with NR were closely associated with N rates above and below 24 kg N ha^{-1}. Similar interaction patterns in leaching were also detected for annual cumulative (Table 1).

A significant $G \times$ NR (i.e., SA vs. CE $\times$ 24.0 vs. 49.0) interaction comparing G type (SA vs. CE) and high

Table 3. Nitrate N leached in response to the interaction of N rate and year average over St. Augustinegrass and centipedegrass during the late winter cycle and annual total from 2006–2009 in Jay, FL. Values in parentheses represent backtransformed values.

	Nitrate N leached					
	2006–2007		2007–2008		2008–2009	
N rate	LWC†	Annual	LWC	Annual	LWC	Annual
kg ha^{-1}	ln (kg ha^{-1})					
0.0	–1.19 (0.7)	2.83 (19.5)	–1.60 (0.3)	0.16 (1.3)	–0.86 (0.5)	0.18 (1.3)
6.0	–1.71 (0.4)	3.10 (23.8)	–1.95 (0.2)	–0.01 (1.1)	–1.18 (0.4)	–0.12 (1.1)
12.5	–1.34 (0.6)	2.84 (18.7)	–1.92 (0.2)	0.10 (1.3)	–0.92 (0.7)	0.10 (1.5)
24.0	–1.74 (0.4)	3.00 (23.6)	–1.92 (0.2)	0.05 (1.1)	–0.53 (0.9)	0.29 (1.7)
49.0	–1.08 (0.9)	3.16 (25.6)	–1.30 (0.5)	0.35 (1.8)	1.83 (9.9)	2.12 (12.5)
$LSD_{0.05}$	NS‡	NS	NS	NS	1.06	0.91

† LWC, late winter cycle, 1 Mar. to 15 Apr.

‡ NS, nonsignificant.

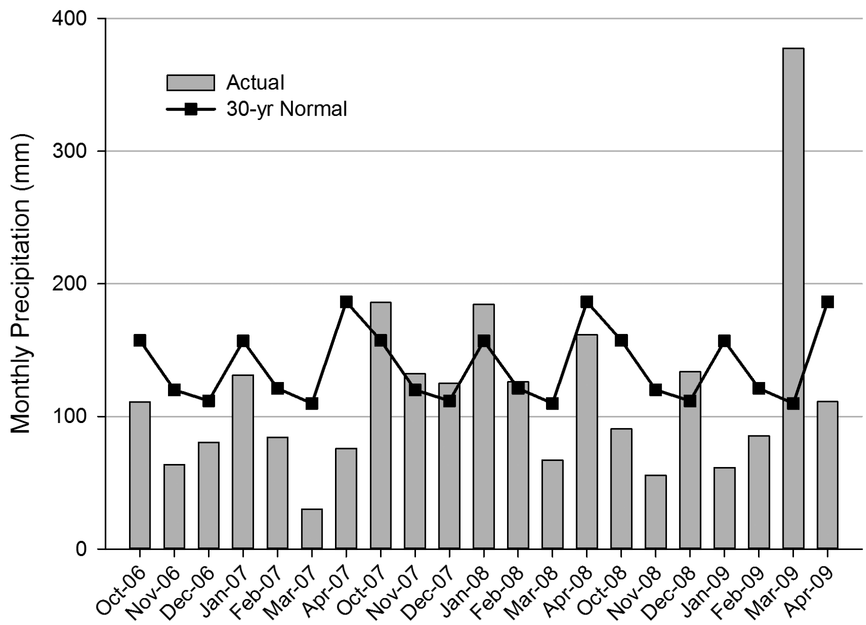

Figure 1. Thirty-year normal and actual rainfall monthly amounts over the 3-yr study period in Jay, FL.

NR (24.0 vs. 49.0 kg N ha^{-1}) was detected during the LWC (Table 1). According to the NR main effects for the single-df contrast comparing 24 vs. 49 kg N ha^{-1}, 49 kg N ha^{-1} promoted greater leaching than the 24 kg N rate during the LWC (Table 1, 2). Additionally, leaching during the LWC was greater with CE than SA. However, differences in leaching between the 24 and 49 kg N rates were dependent on the species (SA vs. CE). At 24 kg N ha^{-1}, leaching rate between the two species were small (0.2 kg N ha^{-1} difference) with values of 0.4 and 0.6 kg ha^{-1} for SA and CE, respectively. Conversely at 49 kg N ha^{-1}, differences in leaching rate between the two species were as large as 1.8 kg N ha^{-1}, with values of 2.9 and 4.7 kg ha^{-1} for SA and CE, respectively. As such, a ninefold greater potential for leaching was observed with CE than SA (0.2 vs. 1.8 kg ha^{-1} difference) as N increased above 24 kg N ha^{-1} during the LWC. A similar $G \times$ NR interaction between species (SA vs. CE) and NR (24.0 vs. 49 kg N ha^{-1}) was also detected in leaching for annual cumulative (Table 1). St. Augustinegrass and CE differed in leaching by only 0.3 kg ha^{-1} (8.7 vs. 9.0 kg ha^{-1}, respectively) at 24 kg N ha^{-1}, while at the 49 kg N ha^{-1} rate, SA and CE differed by as much as 5.7 kg ha^{-1} (10.5 vs. 16.2 kg ha^{-1}, respectively). Thus, as N increased above 24 kg N ha^{-1}, CE showed a 19-fold greater potential for leaching than SA when leaching was cumulated annually.

During the LWC of 2008 to 2009, rainfall exceeded the 30-yr normal by 264 mm (Fig. 1). Nitrate N leaching during 2006 to 2007 exceeded leaching from 2007 to 2008 and 2008 to 2009 for 105 d after initiation (FC and LFC) (Fig. 2). Nitrogen rate had no effect on NO_3–N leaching until 126 DAI in 2008 to 2009. Nitrate N leaching from the 49.0 kg N ha^{-1} rate in 2008 to 2009 exceeded all other N rates at 126, 133, 140, 175, 182, and 203 DAI. After 203 DAI, NO_3–N leaching from the 49.0 kg N ha^{-1} treatment remained greater than all other rates throughout the remainder of the study.

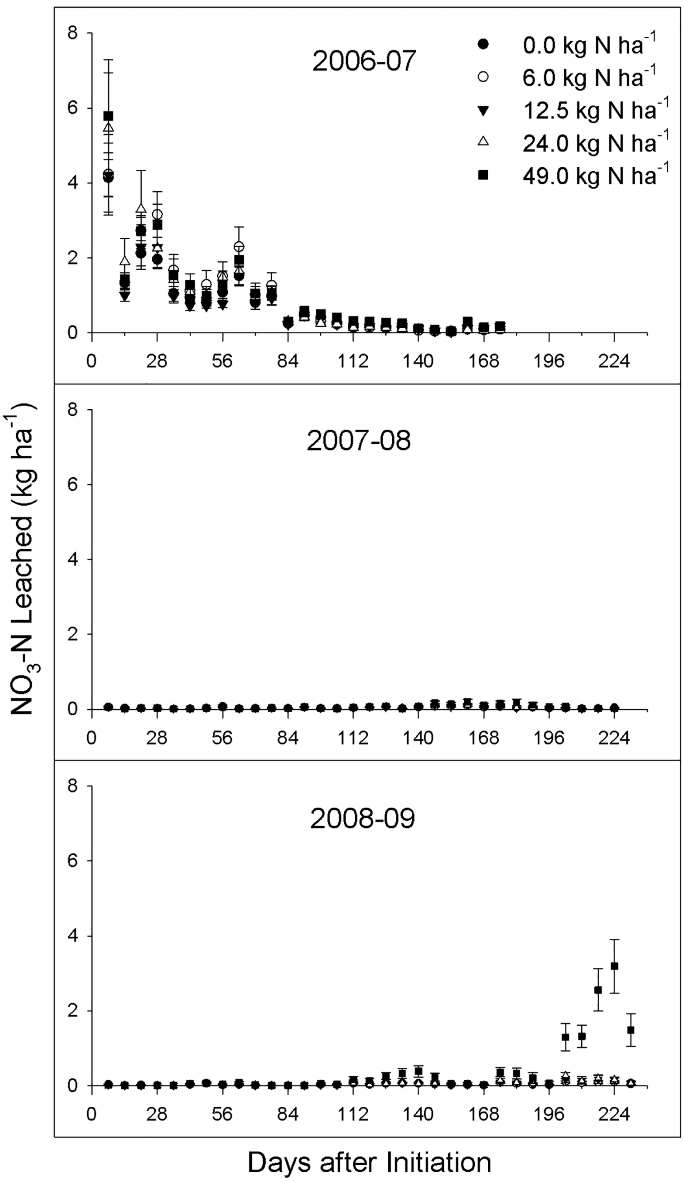

Figure 2. Amount of nitrate N leached (kg ha^{-1}) during each year as influenced by N rate from 2006 to 2008 in Jay, FL. Error bars represent standard error.

DISCUSSION

The largest amount of NO_3–N leached was observed during the FC of 2006 to 2007, which was the first collection cycle following sod installation (Table 2). Increased N leaching following turf establishment has been documented. Shaddox and Sartain (2001) investigated N leaching during the first 12 wk of establishment of 'Tifway' bermudagrass [*Cynodon dactylon* (L.) Pers. × C. *transvaalensis* Burtt Davy)] from sprigging and reported 7 and 9 kg N ha^{-1} leached from ammonium nitrate and ammonium sulfate, respectively. Leached N of 13 kg ha^{-1} in the present study was nearly twofold higher than that reported by Shaddox and Sartain (2001) and likely is due to differences between sprigging and sodding and timing of establishment. Nutrient import from sodding and lack of root system in newly planted SA has been credited with increased N leaching by previous research (Telenko et al., 2015; Trenholm et al., 2013). Sprigs used by Shaddox and Sartain (2001) contained little to no soil and, thus, likely provided little to no N.

Differences between years during the FC continued into the LFC, WC, and LWC. This is contrary to previous research that suggests N leaching following turf establishment is primarily limited to 30 to 60 d following sodding. Erickson et al. (2010) investigated the influence of sod type on NO_3–N leaching from SA, and reported N applications at 30 DAI resulted in no further NO_3–N leaching. The authors attributed this to the sod being well rooted at 30 DAI. However, their research was conducted in the subtropical climate of south Florida, which allows for year-round turfgrass growth. The current study was conducted on sod that was planted in the late summer in north Florida where dormancy conditions exist in the late fall and winter. It is likely that turf establishment was not complete before onset of fall dormancy. If so, this likely caused N leaching to continue beyond 30 d after establishment.

When greater quantities of NO_3–N leached during 2006 to 2007 were compared with other years in the LWC (Table 1), greater amounts of NO_3–N leached from CE than from SA. These findings corroborate those reported by Bowman et al. (2002), who investigated NO_3–N leaching from six warm-season turfgrasses. Following their 12-mo greenhouse study, the authors reported the volume-weighted average of NO_3–N leached from CE was 3.3 compared with 0.9 mg NO_3–N from SA, which was statistically different. The authors attributed lower NO_3–N leaching levels from SA to increases in root length density and leaf N content of SA vs. CE. While tissue and root analyses were beyond the scope of work in the current study, we postulate that N uptake differences between turf species is the primary influencing factor that produced differences in NO_3–N leached. Grasses were maintained at cutting heights recommended for each species. We postulate the greater height of cut for SA may have promoted greater stolon and root growth than CE, thereby enhancing NO_3–N acquisition and reducing NO_3–N leaching. This seems to be particularly plausible, since stolons and roots have been reported to be the primary source of plant storage of N during dormancy (Wherley et al., 2009).

The elevated NO_3–N leaching following sodding continued for 105 DAI (Fig. 2). This is consistent with findings reported by Barton et al. (2009), who investigated various fertilizer regimes during establishment and maintenance of Kikuyugrass (*Pennisetum clandestinum* Holst. ex Chiov.). These authors measured NO_3–N leaching for 2 yr and reported that 50% of total N leached during that time occurred within 120 DAI. Furthermore, the authors concluded that elevated N leaching during turfgrass establishment was due to existing soil N, rather than fertilizer N, as evidenced by similar N leaching levels observed between fertilized and untreated lysimeters. We also observed no difference between fertilized and unfertilized plots during the 105 DAI. The 105 DAI required for NO_3–N leaching levels to become equivalent to NO_3–N leaching from established turf is longer than that reported by Trenholm et al. (2013). Sod in the Trenholm et al. (2013) study was planted in May, while sod in the current study was planted in September. Our later planting date likely prolonged turf establishment and allowed NO_3–N leaching to continue beyond the 60 d reported by Trenholm et al. (2013).

Nitrate N leaching was similar between N rate treatments during each fertilizer cycle until the 2008 to 2009 LWC (Table 2). This is contrary to findings reported by Mangiafico and Guillard (2006). They reported NO_3–N leaching increased the later the date of fall N application compared with untreated turf. However, their study was conducted in Connecticut, where seasonal temperature changes are more pronounced and more severe than north Florida. It is likely that N uptake by turfgrass in north Florida is considerably higher than Connecticut during the fall and winter, and thus, differences between NO_3–N leaching during that same time period would exist.

Analysis of meteorological data provided an explanation for the observed increase in NO_3–N leaching during the LWC of 2008 to 2009. During March 2009, rainfall exceeded the 30-yr normal by ~340%, totaling 377 mm (Fig. 1). Average minimum air and soil temperatures during March 2009 were within 1 to 2°C of March 2007 and 2008 (http://fawn.ifas.ufl.edu); no visible impacts from pathogens, insects, or weeds were noted on either turf species, and no visible signs of winterkill were observed. With the turf appearing healthy and no extreme fluctuations in temperature observed, we postulate that the increase in NO_3–N leaching during LWC 2008 to 2009 was a result of soil accumulation of NO_3–N followed by a significant rainfall event. Other researchers have observed irrigation and rainfall to have an influence on N leaching. Erickson et al. (2010) investigated the influence of irrigation following installation of SA sod, and reported significantly greater NO_3–N leaching occurred when precipitation was highest. Previously, Erickson et al. (2008) investigated N leaching from a mixed species landscape compared with SA and reported greater NO_3–N leaching occurred during the wet season. Reductions in NO_3–N leached from turfgrass have been achieved when water was applied via sensor-based systems compared with daily irrigation regimes (Morton et al., 1988; Snyder et al., 1984), and thus, irrigation practices such as those based on evapotranspiration, wilt, or deficit-irrigation replacement may reduce NO_3–N leaching.

Only the 49 kg N ha^{-1} treatment resulted in greater NO_3–N leaching than untreated turf during the LWC 2008 to 2009. This suggests that winter-applied N may accumulate in the soil and potentially leach if greater than normal rainfall events occur. For this study we did not perform soil N analysis, and thus, soil N data are not available to support this hypothesis. However, our postulation is supported by results from Wherley et al. (2009), who measured recovery of ^{15}N applied to Tifway bermudagrass in North Carolina. The authors reported ^{15}N recovered from plant uptake, soil organic, and soil nitrate during January and August were 21, 10, 69, and 90, 8, and 2% of applied ^{15}N, respectively. Clearly, under dormancy conditions, applied N may be retained as soil nitrate thereby increasing the likelihood of NO_3–N leaching if excessive rainfall events occur. Differing results have been reported (Guertal and Howe, 2012). However, Guertal and Howe (2012) conducted their research on actively growing Tifway bermudagrass and reported soil N remained essentially unaffected by N source, which is likely a result of rapid turf uptake of N and, in turn, lowers soil N to levels equivalent to untreated turf. In the current study, turf remained dormant or quiescent, thus, N uptake was likely lower than that observed during active growth. Increased NO_3 leaching associated with low plant N use and increased rainfall was also observed by Brown et al. (1977).

Fall and winter N applications to turfgrass in Florida are increasing in areas subjected to summer fertilizer bans. We found N applications to warm-season turf during the winter did not pose an increased risk of NO_3–N leaching under normal rainfall conditions. However, the influence of late-season N applications on the quality of warm-season turf has not been investigated. Thus, until such studies have been published on warm-season turf, recommending N application to warm-season turf during the winter may be a questionable practice.

CONCLUSIONS

We found N applied at rates of 49 kg N ha^{-1} in water-soluble form during suboptimal growth periods may increase N leaching with dormant warm-season turf under excessive rainfall conditions. Elevated NO_3–N leaching levels were observed for ~3 mo following planting. However, N applications during this time period did not increase NO_3–N leaching compared with untreated turf. While this conclusion suggests N applications during sodding pose limited environmental threat, we used foliar-applied urea at low N rates, which may substantially differ from granular N sources, higher N rates, or slowly available N forms. Applying fall fertilizer at rates ≤24 kg N ha^{-1} to SA or CE during winter months in Florida did not pose an increased risk to NO_3–N leaching when compared with untreated turf, even when subjected to excessive rainfall. However, the 49.0 kg N ha^{-1} treatment increased NO_3–N leached above untreated turf during the LWC because of a significant rainfall event (377 mm) in March 2009. Additionally, greater risk of NO_3–N leaching was observed from CE than from SA when 49 kg N ha^{-1} was applied during the establishment year. While our research suggests limited NO_3–N leaching occurs when soluble N is applied to dormant, warm-season turf, the benefits of N applications on turf quality and growth during the winter remains uncertain. This issue must be clarified before N applications to dormant turf are recommended.

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