RESEARCH

# Nitrate Leaching, Turf Quality, and Growth Rate of 'Floratam' St. Augustinegrass and Common Centipedegrass

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## ABSTRACT

Turf fertilization in Florida continues to be viewed as contributing to nonpoint-source pollution of ground water. Continued research is needed to validate existing best management practices (BMPs). The objectives of this research were to evaluate nitrate-N ($NO_3$–N) leaching, turf quality, and turf growth rate from N sources applied to 'Floratam' St. Augustine grass [*Stenotaphrum secundatum* (Walter) Kuntze] and common centipede grass [*Eremochloa ophiuroides* (Munro) Hack.]. Research was conducted in Jay, FL, from 2008 to 2011. Nitrogen was applied in 60-d cycles at 48 kg ha$^{-1}$ as ammonium nitrate, urea, 30% slow-release N (SRN), 50% SRN, polymer-coated urea (PCU), and biosolid (BS) and in 120-d cycles at 98 kg ha$^{-1}$ as PCU. Nitrogen leaching was greatest during the first 6 mo following turf sodding for both species with 21.6 and 10.1 kg ha$^{-1}$ leached from St. Augustinegrass and centipedegrass, respectively. Following sodding, no differences in N leached between turfgrasses were observed until 2010 when winterkill and large patch (*Rhizoctonia solani* Kühn) were observed on St. Augustinegrass. Turf quality of control plots was above acceptable levels in 2008 but was unacceptable by 2011. Each N source produced acceptable centipedegrass with few differences among N sources. A blend of 50% ammonium sulfate and 50% PCU resulted in higher growth rates and turf quality of St. Augustinegrass than other N sources in most years. Recommending N applications to newly sodded turf may not be necessary due to the risk of leaching during establishment.


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**Abbreviations:** BMP, best management practice; BS, biosolid; HDPE, high-density polyethylene; MDL, minimum detection limit; PCSCU, polymer-coated sulfur-coated urea; PCU, polymer-coated urea; SRN, slow-release N.

In Florida, lawn and landscape fertilization practices continue to be implicated as contributing to nonpoint-source pollution of ground water. In response, commercial fertilizer applicators must now follow BMPs for the Green Industries in Florida (FDEP, 2010) and possess a state fertilizer license issued by Florida Department of Agriculture and Consumer Services (Florida Statute 576.021). However, more restrictive local ordinances that exceed the BMPs continue to be implemented throughout Florida (Hochmuth et al., 2012). Numerous studies have documented factors influencing N leaching from turfgrass. These factors include N application rate, N source, turf type, turf condition, and precipitation.

Trenholm et al. (2013) applied urea to newly sodded Floratam St. Augustinegrass at various rates. Investigators reported that when rates increased from 2.5 to 20 kg ha$^{-1}$ within the first 60 d after application, leached $NO_3$–N increased from 0.7 to 5.7 kg ha$^{-1}$ in the first year and from 1.6 to 4.0 kg ha$^{-1}$ in the second year. During a two-year study on 10-yr-old Kentucky bluegrass (*Poa pratensis* L.), Frank et al. (2006) reported similar findings when low- and high-N rates (98 and 245 kg ha$^{-1}$ yr$^{-1}$, respectively) leached 0.3

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and 5.0 kg ha$^{-1}$. Authors hypothesized that the observed increase in N leached with the high fertilization rate was due to N applications exceeding turf demand.

Several investigators have reported that N leaching is influenced by N source. Guillard and Kopp (2004) applied ammonium nitrate, polymer-coated sulfur-coated urea (PCSCU), and a natural organic N source to a mixture of cool-season lawn turfgrasses and reported the flow-weighted $NO_3$–N concentration was higher from ammonium nitrate (4.6 mg L$^{-1}$) than from either PCSCU (0.57 mg L$^{-1}$) or the organic treatment (0.31 mg L$^{-1}$). Investigators further noted that neither PCSCU nor the natural organic increased flow-weighted $NO_3$–N concentration above that of untreated turf. Wu et al. (2010) investigated N source effects on N leaching using ammonium nitrate, PCU, natural organic, and methylene urea. The authors reported all three SRN sources resulted in lower nitrate concentration in leachate than ammonium nitrate. When investigating N leaching from 'Tifway' hybrid Bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt Davy] on a sand soil, Guertal and Howe (2012) observed in the first year of investigation that cumulative $NO_3$–N leached from urea and a urea and nitrification inhibitor (UMAXX; JR Simplot Co.) (~600 mg) was greater than $NO_3$–N leached from PCU or the control (~300 mg). The authors further noted that $NO_3$–N leached from PCU treated turfgrass during the first year was similar to the control. Similar findings were reported by Petrovic (2004) when both 100- and 200-d PCU-treated turfgrass leached similar total N as untreated turfgrass over 3 yr.

Turf species and turfgrass health have been reported to influence N leaching. Bowman et al. (1998) investigated the influence of N leaching through two bentgrass species (*Agrostis* spp.) and reported that N leaching losses of 26.5 mg L$^{-1}$ from shallow-rooted turf was reduced to 13.5 mg L$^{-1}$ when applied to deep-rooted turf. Bowman et al. (2002) investigated N leaching losses from six warm-season turfgrasses in a greenhouse study and reported 'Raleigh' St. Augustinegrass and Tifway hybrid Bermudagrass were the most efficient at reducing N leaching while 'Meyer' (*Zoysia japonica* Steud.) and 'Emerald' zoysiagrass (*Zoysia japonica* × *Z. tenuifolia*) were least efficient. The authors associated differences between species with a larger root length density from St. Augustinegrass and Bermudagrass compared with Meyer and Emerald zoysiagrass. Engelsjord and Singh (1997) investigated N leaching during establishment of Kentucky bluegrass and noted that leached $NO_3$–N concentrations peaked at 63 mg L$^{-1}$ during the first month of establishment. Concentrations fell to below 5 mg L$^{-1}$ within 2 mo. Furthermore, while investigators were unable to compare $NO_3$–N leaching between years, they did note a decrease in N leaching from 2-mo-old turf compared with newly seeded turf and attributed this effect to an increase in N uptake. Snyder and Cisar (2000) investigated N leaching during establishment of 'Tifdwarf' Bermudagrass on sand-based golf greens in Florida and reported N concentrations ranged from 20 to nearly 200 mg L$^{-1}$. After establishment, the authors reported N concentrations fell to below 10 mg L$^{-1}$.

While the Florida BMPs provide science-based guidelines for the application of nutrients to lawn and landscapes, validation and verification of BMPs ensure their success. Improving the understanding of the effects of N type and form applied to St. Augustinegrass and centipedegrass will assist in further developing turf BMPs. Research investigating N leaching from various N sources applied to newly sodded St. Augustinegrass and centipedegrass is limited, particularly during the initial months following sod installation. The objective of this study was to determine the influence of N source on $NO_3$–N leached and turf growth response from Floratam St. Augustinegrass and common centipedegrass.

## MATERIALS AND METHODS

This study was conducted from 2008 until 2011 at University of Florida's West Florida Research and Education Center in Jay, FL (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 turfgrass species in 12- by 12-m main plots and N source treatments in 3- by 6-m subplots. Main plots and subplots were arranged in a randomized complete block design using four replications.

High-density polyethylene (HDPE) drainage 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 in diameter 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 tubing (0.95-cm low-density polyethylene) was attached. Connected tubing ran underground to a central, aboveground leachate collection terminal. 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. 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 before plot preparation for sodding using a laser-transit-controlled, wheeled-box blade. Sod grown on a mineral soil was harvested and plots were sodded with common centipedegrass and Floratam St. Augustinegrass the week of 20 July 2008.

Treatments consisted of seven fertilizer sources and an untreated control (Table 1). All treatments, except PCU2, were applied on 19 Aug. 2008; 15 Apr., 12 June, 13 Aug., and 9 Oct. 2009; 15 Apr., 11 June, 9 Aug., and 8 Oct. 2010; and 12 Apr. and 11 June 2011. The PCU2 was applied every 120 d such that applications were on 19 Aug. 2008; 15 Apr. and

**Table 1. Fertilizer treatments applied to turfgrass.**

| Treatment† | Source | Grade (N-P-K) | Information | N application rate |
|---|---|---|---|---|
| | | | | kg ha$^{-1}$ |
| Control | | | | 0 |
| Ammonium nitrate | Crop Production Services (Jay, FL) | 33.5-0-0 | 16.75 ammoniacal N, 16.75 nitrate N | 49 |
| Urea | Crop Production Services | 46-0-0 | 46% urea N | 49 |
| 30% SRN† | John Deere Landscapes (Pensacola, FL) | 16-0-6.6 | 11.2% urea N, 4.8% sulfur-coated urea, 8% $K_2O$ as potassium chloride | 49 |
| 50% SRN | Harrell's LLC (Lakeland, FL) | 19-0-15.7 | 9.52% ammoniacal N, 9.48% polymer-coated urea (42-0-0), 19% $K_2O$ as potassium chloride | 49 |
| PCU1 | Harrell's LLC | 41-0-0 | 41% polymer-coated urea | 49 |
| PCU2 | Harrell's LLC | 41-0-0 | 41% polymer-coated urea | 98 |
| BS | Milorganite (Milwaukee, WI) | 6-0.8-0 | Municipal solid waste | 49 |

† BS, biosolid; PCU, polymer-coated urea; SRN, slow-release nitrogen.

13 Aug. 2009; 15 Apr., and 9 Aug. 2010; and 12 Apr. 2011. In 2008, only one application of N was applied on 19 August due to late-season implementation.

Leachate samples were collected by removing all leachate from each lysimeter by vacuum extraction. Leachate volumes were measured for each leachate collection and a 20-mL subsample was acquired for $NO_3$–N + $NO_2$–N analysis from each lysimeter. Sampling began 5 Aug. 2008 and ended 15 Dec. 2008. Sample collection resumed 17 Feb. 2009 and continued on a weekly basis until the completion of the trial on 30 Aug. 2011. 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. Results are reported as monthly and annual $NO_3$–N mass flux. Percentage of applied N leached was determined by subtracting the amount of N leached from the untreated control from each treatment.

Turfgrass quality was evaluated biweekly when turf was actively growing using a scale of 1 to 9, where 1 = dead/brown turf and 9 = optimal healthy/green turf. A rating of 6 was considered acceptable for a home lawn. Winter injury and disease incidence were assessed when observed. Turfgrass clippings were sampled biweekly following each fertilizer application. Clippings were collected from subplots using a rotary mower set to cut at a height of 5.0 cm and 7.6 cm for centipedegrass and St. Augustinegrass, respectively, and represented approximately 7 d growth. Samples were dried under 50°C forced air for 48 to 72 h before measuring masses.

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 Corporation) rotary irrigation heads set to deliver 0.5 mm water min$^{-1}$. 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 with run times being adjusted to provide approximately 80% of previous week's evapotranspiration.

PROC general linear model (SAS Institute, 2010) was used to analyze data, testing for significance of main effects and interactions, and means were separated using Fisher's protected LSD ($p$ = 0.05). Leachate data were found to be normally distributed and type III errors were adjusted for a split-plot design.

**Table 2. Analysis of variance of $NO_3$–N leached, percentage of applied N leached, growth rate, and quality in response to year and N source of St. Augustinegrass and centipedegrass from 2008 to 2011 in Jay, FL.**

| Source of variation | — $NO_3$–N leached — | | Growth rate | Turf quality† |
|---|---|---|---|---|
| | kg ha$^{-1}$ | % applied N | | |
| Year (Y) | *** | *** | *** | *** |
| Grass (G) | *** | ** | *** | *** |
| N Source (N) | *** | *** | *** | *** |
| Y × G | ** | NS‡ | NS | *** |
| Y × N | *** | *** | *** | *** |
| G × N | ** | * | *** | *** |
| Y × G × N | NS | NS | *** | *** |

* Significant at $P \leq 0.05$.

** Significant at $P \leq 0.01$.

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

† Turf quality based on a scale of 1 to 9, where 1 = dead/brown turf, 9 = optimal healthy/green turf, and 6 = minimally acceptable.

‡ NS, nonsignificant.

## RESULTS AND DISCUSSION

### Nitrate-Nitrogen Leaching

Interactions of year ($Y$) × grass ($G$), $Y$ × N source ($N$), and $G \times N$ were significant for both total $NO_3$–N and percentage applied N leached (Table 2). Nitrate-N and percentage applied N leached was not affected by the $Y \times G \times N$ interaction. Thus, the influence of turfgrass and year on total $NO_3$–N and percentage applied N leached was determined within each N source. Due to the rapid oxidation of N species in arable soils, $NO_3$–N has been the dominant N species found in many turfgrass leaching studies (Bowman et al., 2002; Erickson et al., 2010). Previous researchers have found the presence of $NH_4$–N in turfgrass leaching studies to be lower than the detection limit (Geron et al., 1993; Quiroga-Garza et al., 2001), thus, we analyzed for $NO_3$–N and $NO_2$–N as have previous researchers (Bowman et al., 1998; Exner et al., 1991; Trenholm et al., 2013).

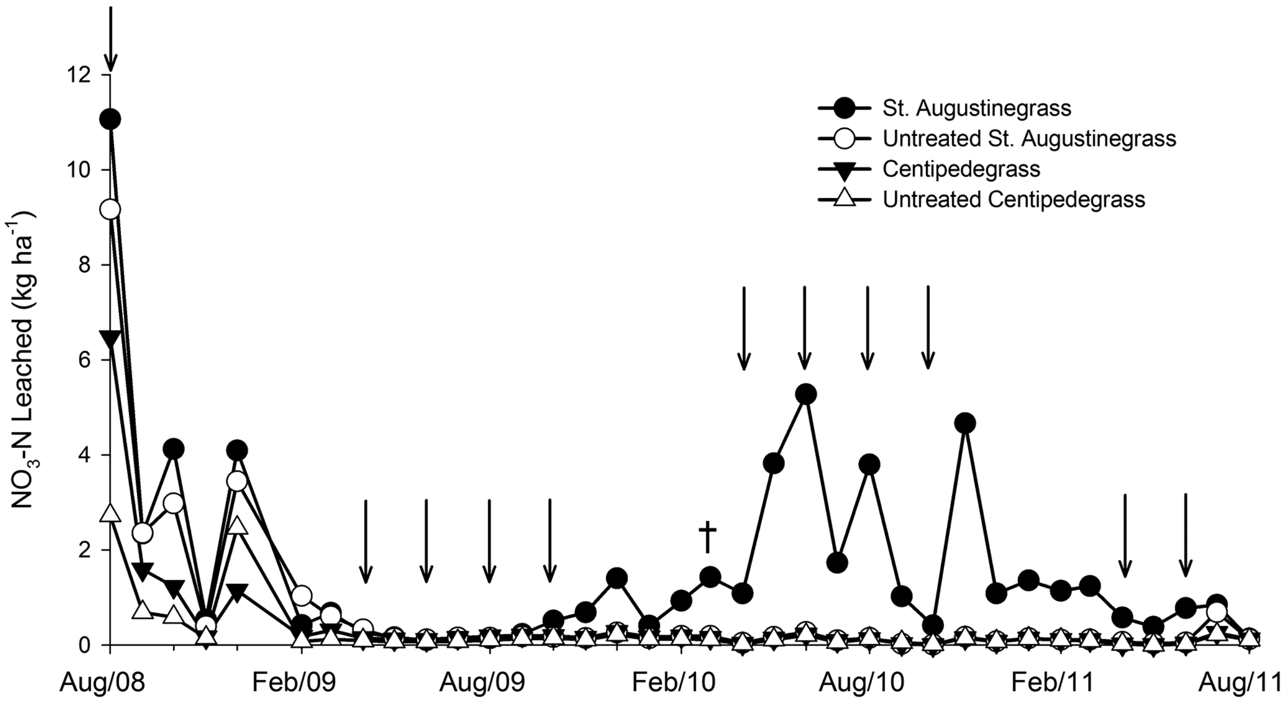


Figure 1. Monthly total $NO_3$–N averaged across N sources leached from St. Augustinegrass and centipedegrass during the 3-yr study period in Jay, FL. Arrows denote treatment applications. First recorded turf damage from large patch (*Rhizoctonia solani* Kühn) and winterkill denoted by †.

Nitrate-N leaching was highest for St. Augustinegrass and centipedegrass during the first 6 mo following sodding (Fig. 1). Initial $NO_3$–N leaching from centipedegrass was 6 kg $ha^{-1}$ in August 2008 declining to 0.5 kg $ha^{-1}$ by February 2009. Following May 2009, $NO_3$–N leaching remained <0.06 kg $ha^{-1}$ throughout the remaining 2.5 yr for treated and untreated centipedegrass. The increased $NO_3$–N leaching during the first 6 mo following sodding was likely attributed to nutrients imported with the sod, increased N mineralization both within the sod and in the existing soil, and absence of roots below the sod–soil interface. Indication of nutrient import or N mineralization following sodding is shown by the associated increase in $NO_3$–N leaching from plots receiving no N. Similar findings were reported by Geron et al. (1993), who investigated $NO_3$–N leaching from 'Baron' Kentucky bluegrass for 2.5 yr following sodding. They reported the monthly average $NO_3$–N concentration during the first month following sodding was 15.0 mg $L^{-1}$. After the initial 12 mo, $NO_3$–N concentrations reduced to <2.0 mg $L^{-1}$. The authors attributed the increased $NO_3$–N leaching during the initial months to increases in N mineralization, which occurred due to soil disruption during the preparation process. In the present study, similar trends during the first 6 mo were observed with St. Augustinegrass. However, beginning in January 2010, $NO_3$–N leaching from St. Augustinegrass increased from <0.05 kg $ha^{-1}$ to a peak of 4.8 kg $ha^{-1}$ in June 2010 (Fig. 1). Leaching levels declined to approximately 1.0 kg $ha^{-1}$ by December 2010 but remained >0.3 kg $ha^{-1}$ until the end of the study. The likely explanation of increased N leaching in 2010 was winterkill and large patch incidence on St. Augustinegrass (Table 3), which was initially observed in March 2010 and was likely caused by 14 consecutive days below 0°C beginning on 2 Jan. 2010 (http://fawn.ifas.ufl.edu). The damaged St. Augustinegrass was in a recovery phase throughout spring and early summer 2010, thus, $NO_3$–N leaching levels increased to levels observed during the first 6 mo following sodding. Turf leaching research has focused primarily on $NO_3$–N leaching during normal turf growth phases such as establishment, active growth, and dormancy. Little is known

**Table 3. Large patch and winterkill descriptive statistics on St. Augustinegrass and centipedegrass on 19 Mar. 2010 in Jay, FL.**

| | St. Augustinegrass | Centipedegrass |
|---|---|---|
| | % of plot affected | |
| Winterkill | | |
| *n* | 32.0 | 32.0 |
| Minimum | 0.0 | 0.0 |
| Maximum | 70.0 | 0.0 |
| Median | 10.0 | 0.0 |
| Mean | 15.0 | 0.0 |
| Quartile 1 | 0.0 | 0.0 |
| Quartile 3 | 25.0 | 0.0 |
| Large Patch | | |
| *n* | 32.0 | 32.0 |
| Minimum | 0.0 | 0.0 |
| Maximum | 70.0 | 10.0 |
| Median | 0.0 | 0.0 |
| Mean | 20.0 | 0.3 |
| Quartile 1 | 0.0 | 0.0 |
| Quartile 3 | 50.0 | 0.0 |

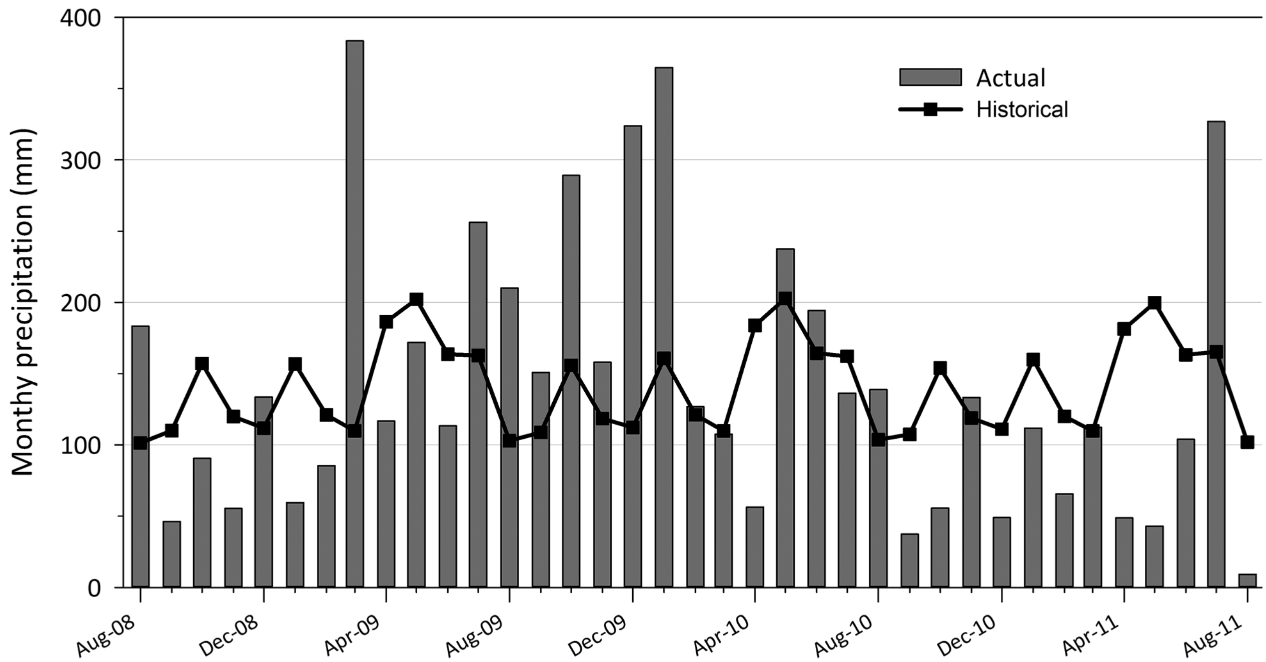


Figure 2. Historical (30-yr) and actual rainfall for each month research was conducted over the 3-yr study period in Jay, FL.

about the influence of winterkill on $NO_3$–N leaching from turfgrass, which is likely due to the difficulty involved with relying on a natural winterkill to occur during a controlled leaching study. Although the influence of winterkill on N leaching has not been well documented, the influence of disease on N leaching was documented by Trenholm et al. (2012). The authors investigated $NO_3$–N leaching due to N rate from St. Augustinegrass and zoysiagrass and reported increased $NO_3$–N from zoysiagrass at high N rates was due to increased presence of large patch disease. The researchers applied a fungicide and, by late summer, turf growth resumed with increased turf cover leading to decreased $NO_3$–N leaching. Although investigating winterkill and large patch was beyond the intended scope of this study, we believe winterkill and large patch were the primary influencing factors resulting in increased $NO_3$–N leaching during 2010. We considered the influence of rainfall, particularly since other investigators have noted a correlation between irrigation and rainfall events and N leaching (Balkcom et al., 2003; Barton and Colmer, 2006; Erickson et al., 2010; Snyder et al., 1984). However, on observation of actual and 30-yr average rainfall (Fig. 2), no correlation was found (analysis not presented). Moreover, monthly totals exceeding the 30-yr average primarily occurred during 2009 when N leaching was lowest. In 2010, when N leaching was high, rainfall was generally low.

Turfgrass species influenced $NO_3$–N leaching (Table 4). During the establishment year of 2008, 21.6 and 10.1 kg ha$^{-1}$ leached from St. Augustinegrass and centipedegrass, respectively. Although nutrient application before sod harvest were uncertain, BMPs recommended on-farm N applications would be 224 and 134 kg ha$^{-1}$ for St. Augustinegrass and centipedegrass, respectively (FDACS, 2008). Thus, N leaching differences during the establishment year were likely due to differences in sod farm nutrient management practices. In 2009 and 2011, turfgrass did not influence N leaching, while in 2010, N leaching from St. Augustinegrass and centipedegrass was 19.5 and 0.9 kg ha$^{-1}$, respectively. In 2009 and 2011, both turfgrasses grew under normal environmental conditions and no visual turfgrass stress normally associated with deficient water, light, or temperature was observed. Thus, N leaching from each turfgrass was similar. However, in the late winter of 2010, winterkill and large patch were observed primarily on St. Augustinegrass (Table 3). This resulted in increased N leaching as previously discussed.

**Table 4. Nitrate N leached as kg ha$^{-1}$ in response to the interaction of year and turf from St. Augustinegrass and centipedegrass between 2008 and 2011 in Jay, FL.**

| | $NO_3$–N leached | | | |
|---|---|---|---|---|
| | 2008 | 2009 | 2010 | 2011 |
| | kg ha$^{-1}$ | | | |
| St. Augustinegrass | 21.6a† | 2.3a | 19.5a | 2.1a |
| Centipedegrass | 10.1b | 1.1a | 0.9b | 0.4a |

† Values within columns followed by the same letter do not differ according to Fisher's least significant difference (*P* = 0.05).

When analyzed within N sources, greater N leaching was observed when treatments were applied to St. Augustinegrass than to centipedegrass with the only exception being PCU1 when N leaching was similar between turfgrasses (Table 5). When no N was applied, N leaching from St. Augustinegrass and centipedegrass was observed to be 5.4 and 2.1 kg ha$^{-1}$, respectively, when

Table 5. Total $NO_3$–N leached as kg $ha^{-1}$ and percentage applied in response to the interaction of grass and N source and the interaction of year and N source from St. Augustinegrass and centipedegrass between 2008 and 2011 in Jay, FL.

| | NO$_3$–N leached | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Control | AN† | Urea | 30% SRN‡ | 50% SRN | PCU1§ | PCU2 | BS¶ |
| | kg ha$^{-1}$ | | | | | | | |
| Turf | | | | | | | | |
| St. Augustinegrass | 5.4a# | 17.4a | 15.6a | 17.5a | 9.6a | 4.6a | 15.9a | 5.0a |
| Centipedegrass | 2.1b | 3.7b | 1.4b | 7.5b | 3.4b | 3.4a | 1.9b | 1.7b |
| Year | | | | | | | | |
| 2008 | 12.4a | 21.6a | 8.7ab | 32.9a | 17.2a | 10.8a | 15.9a | 7.5a |
| 2009 | 0.9b | 2.2b | 2.7b | 2.2b | 2.0b | 0.8b | 1.8b | 1.0b |
| 2010 | 0.9b | 17.7a | 20.9a | 13.5a | 6.2b | 3.1b | 15.1a | 3.9ab |
| 2011 | 0.7b | 0.7b | 1.6b | 1.3b | 0.6b | 1.5b | 2.9b | 0.8b |
| | % Applied N | | | | | | | |
| Turf | | | | | | | | |
| St. Augustinegrass | NA | 7.8a | 4.9a | 8.8a | 2.7a | –1.2a | 6.9a | –1.2a |
| Centipedegrass | NA | 1.4b | –0.8b | 5.4a | 1.3a | 1.3a | –0.2b | –0.5a |
| Year | | | | | | | | |
| 2008 | NA | 9.2a | –3.8b | 20.8a | 4.8a | –1.7a | 3.5a | –5.0b |
| 2009 | NA | 0.6b | 0.8b | 0.6b | 0.5a | –0.1a | 0.4a | 0.1a |
| 2010 | NA | 8.5a | 10.2a | 6.4ab | 2.7a | 1.1a | 7.2a | 0.1a |
| 2011 | NA | 0.1b | 0.9b | 0.7b | –0.1a | 0.8a | 2.3a | 1.5a |

† AN, ammonium nitrate.

‡ SRN, slow-release nitrogen.

§ PCU, polymer-coated urea.

¶ BS, biosolid.

# Values within columns followed by the same letter do not differ according to Fisher's least significant difference ($P$ = 0.05).

averaged across all years. However, from untreated turf, 83% of N leaching from both turfgrasses occurred during the establishment year. After the establishment year, leached N was equivalent among years with approximately 0.9 kg $ha^{-1}$ leached annually from untreated turf. With the exceptions of 50% SRN and PCU1, N leached from each N source in 2010 was equivalent to N leached during 2008, which corresponded with the onset of winterkill and large patch. Since increased N leaching in 2010 was not observed from untreated turf, this may suggest that N applications may have exacerbated the winterkill–large patch phenomenon and, thus, indirectly contributed to N leaching. Other researchers have observed increased large patch activity on turfgrass fertilized at similar N rates as used in the current study (Burpee, 1995; Cutulle et al., 2014). No differences in N leaching were observed between years 2009 and 2011 from any N source and N leached ranged from 2.7 to 0.6 kg $ha^{-1}$.

Percentage of applied N leached was greater in St. Augustinegrass than centipedegrass when ammonium nitrate, urea, and PCU2 were applied, while no differences between turfgrasses were observed from other N sources (Table 5). As soluble N, both ammonium nitrate and urea are more prone to leaching than slow-release products (Guertal and Howe, 2012). The observed increase in N leaching from PCU2 was likely due to PCU2 being the only N source applied at 98 kg $ha^{-1}$.

When St. Augustinegrass succumbed to winterkill in 2010, applications of ammonium nitrate and urea resulted in a higher percentage of applied N leached than in either 2009 or 2011. Centipedegrass has been reported to have better freezing resistance than St. Augustinegrass (Fry and Huang, 2004). As a healthy sward, centipedegrass produced approximately 21% less $NO_3$–N leaching than St. Augustinegrass throughout the study. While N leaching differences between turf species have been documented (Bowman et al., 2002) and may have played a role in this study, few differences between $NO_3$–N leaching between species were observed before the January 2010 injury endured by St. Augustinegrass (Fig. 1). Thus, we believe turf stress due to winterkill was the primary cause of increased $NO_3$–N leaching in this case. This suggests N sources may have a greater influence on N leaching on stressed turf than on healthy turf.

Application of BS to St. Augustinegrass and centipedegrass resulted in −1.2 and −0.5% of applied N leached. Furthermore, BS produced −5.0% of applied N leached in 2008, which was less than 2009, 2010, or 2011. Reductions in N leaching from organic N sources have been noted by previous research (Guillard and Kopp, 2004) and may be attributed to N immobilization produced by their elevated carbon content. However, other research has reported the percentage of applied N leached from BS is equivalent to other SRN sources (Petrovic, 2004).

Table 6. Growth rate and quality of St. Augustinegrass and centipedegrass influenced by N source by year from 2008 to 2011 in Jay, FL.

| N Source† | St. Augustinegrass 2008 | St. Augustinegrass 2009 | St. Augustinegrass 2010 | St. Augustinegrass 2011 | Centipedegrass 2008 | Centipedegrass 2009 | Centipedegrass 2010 | Centipedegrass 2011 |
|---|---|---|---|---|---|---|---|---|
| Growth rate‡ | | | | kg ha$^{-1}$ d$^{-1}$ | | | | |
| Control | 1.9ab§ | 0.4e | 0.3d | 0.3d | 9.4d | 3.3d | 3.3d | 4.4f |
| Ammonium nitrate | 2.2ab | 1.5bc | 1.1c | 2.5bc | 15.5a | 13.5a | 12.6ab | 14.1bcd |
| Urea | 2.5a | 1.2cd | 0.9c | 1.4cd | 12.9a–d | 11.2b | 11.5b | 15.0abc |
| 30% SRN§ | 2.2ab | 1.6bc | 1.7b | 2.4c | 14.9ab | 10.7b | 13.2a | 12.4de |
| 50% SRN | 1.7ab | 2.4a | 2.5a | 4.3a | 14.3abc | 11.4b | 13.4a | 12.5cde |
| PCU¶1 | 0.8b | 0.9de | 1.5bc | 3.9ab | 9.6d | 7.5c | 12.7ab | 15.5ab |
| PCU2 | 1.3ab | 1.9ab | 1.3bc | 4.2a | 11.8bcd | 13.4a | 12.0ab | 16.9a |
| BS# | 1.4ab | 0.6de | 1.0c | 2.1c | 10.8cd | 6.2c | 8.7c | 10.0e |
| Turf quality¶ | | | | Scale of 1–9 | | | | |
| Control | 7.2c | 4.4d | 4.5e | 3.6f | 7.0e | 6.1c | 5.6e | 4.8d |
| Ammonium nitrate | 8.0a | 6.8ab | 5.8d | 4.8e | 8.3a | 8.3a | 8.5a | 7.2abc |
| Urea | 7.8ab | 6.9a | 6.0cd | 5.1de | 8.0abc | 8.1a | 8.4ab | 7.0bc |
| 30% SRN | 7.8ab | 6.8ab | 7.1a | 6.9ab | 8.0ab | 8.1a | 8.0c | 7.1abc |
| 50% SRN | 7.7ab | 6.9a | 7.5a | 7.2a | 7.8bc | 8.2a | 8.2bc | 6.9c |
| PCU1 | 7.2c | 6.3b | 6.9ab | 5.8cd | 7.0e | 7.7b | 8.3ab | 7.3ab |
| PCU2 | 7.2c | 6.5ab | 6.2bcd | 5.3de | 7.3de | 8.3a | 8.4ab | 7.5a |
| BS | 7.6bc | 5.8c | 6.7abc | 6.4bc | 7.5cd | 7.5b | 7.7d | 7.4ab |

† BS, biosolid; PCU, polymer-coated urea; SRN, slow-release nitrogen.

‡ Average of collection cycles.

§ Values within columns followed by the same letter do not differ according to Fisher's least significant difference ($P = 0.05$).

¶ Turf quality based on a scale of 1 to 9, where 1 = dead/brown turf, 9 = optimal healthy/green turf, and 6 = minimally acceptable.

## Turf Growth and Quality

Both average growth rate and average turf quality were influenced by the interaction of $Y \times G \times N$ (Table 2). Thus, the influence of N source on growth rate and turf quality was determined by year within each species. Although differences were observed between grasses and between years for growth rate and quality, the significance of the $Y \times G \times N$ interaction prevented any direct comparisons of main effects.

In 2008, N sources did not increase growth rate of St. Augustinegrass above the control (Table 6). However, growth rate of centipedegrass was influenced by N source with ammonium nitrate, 30% SRN, and 50% SRN, producing growth rates of 15.5, 14.9, and 14.3 kg ha$^{-1}$ d$^{-1}$, respectively, while the control differed by producing 9.4 kg ha$^{-1}$ d$^{-1}$. Each N source produced similar St. Augustinegrass growth rates except urea, which produced a higher growth rate than PCU1 at 2.5 and 0.8 kg ha$^{-1}$ d$^{-1}$, respectively. Increased growth with urea than with the equivalent amount of N from PCU is reasonable, particularly during turf establishment. Once applied, urea is immediately hydrolyzed and nitrification can begin. Urea diffusion from PCUs may be slower than desired, particularly on thicker-coated materials such as the 41-0-0 used in this study (Connell et al., 2011). During the time required for urea diffusion across the polymer membrane, turf may be deprived of N, resulting in growth rates equal to plots receiving no N. This occurred during the establishment year for both turf species in this study. It is possible that PCUs may be suitable for turf establishment if thinner coatings or higher rates are used. In either case, greater N would be available during the initial weeks after sodding and turf demand for N may be more sufficiently met.

In 2008, all treatments produced acceptable quality St. Augustinegrass and centipedegrass (Table 6). Ammonium nitrate, urea, 30% SRN, and 50% SRN produced higher St. Augustinegrass quality than did control PCU1 or PCU2. Centipedegrass quality was not increased by the application of PCU1 or PCU2, which produced turf qualities similar to the untreated control. As previously discussed, N rate and coating thickness have a pronounced influence on N release from PCUs. In this case, N release from PCUs was likely too slow to meet turf demand. Nitrogen sources containing soluble N resulted in better quality turf than SRN sources.

In 2009, only PCU1 and BS resulted in similar St. Augustinegrass growth rates as the control. Additionally, the 50% SRN produced a growth rate of 2.4 kg ha$^{-1}$ d$^{-1}$, which was higher than any other N source except PCU2. Each N source produced centipedegrass growth rates greater than the control. Ammonium nitrate and PCU2 produced higher centipedegrass growth rates than all other N sources with 13.5 and 13.4 kg ha$^{-1}$ d$^{-1}$, respectively. Among N sources, the PCU1 and BS treatments produced the lowest centipedegrass growth rates with 7.5 and 6.2 kg ha$^{-1}$ d$^{-1}$, respectively. Beginning in 2009, turf quality of untreated St. Augustinegrass fell below acceptable limits and remained unacceptable through the remainder of the study (Table 6). Additionally, in 2009, the only N source that failed to produce acceptable quality St. Augustinegrass was BS at 5.8. Conversely, all treatments including the control produced acceptable quality centipedegrass. Due to the N requirements of centipedegrass, Florida BMPs recommend approximately 40% less N to be applied to centipedegrass than to St. Augustinegrass (FDEP, 2010). It appears the N mineralization rate from the untreated centipedegrass plots was sufficient to provide the centipedegrass with sufficient N to produce acceptable quality turf, while in St. Augustinegrass that demand was not met.

In 2010, each N source produced higher St. Augustinegrass and centipedegrass growth rates than the control. St. Augustinegrass growth rate from 50% SRN was 2.5 kg $ha^{-1}$ $d^{-1}$ and was higher than all other N sources. In centipedegrass, differences between N sources were minimal with ammonium nitrate, 30% SRN, 50% SRN, PCU1, and PCU2 all producing equivalent growth rates. In 2010, ammonium nitrate and the control produced unacceptable St. Augustinegrass quality. The 30% SRN and 50% SRN produced the highest St. Augustinegrass qualities at 7.1 and 7.5, respectively, and were similar to PCU1 and BS. Each N source produced centipedegrass quality equal to or greater than 8.0 except BS, which differed from other N sources at 7.7. In most years, BS produced turf quality for both species above the control but was lower than most other N sources. Sartain (1999) noted that Milorganite (Milorganite) compared less favorably to other natural organic N sources for turf quality, stating that N mineralization was too gradual. Carrow (1997) noted Milorganite was unable to produce turf quality and shoot growth equal to urea. However, when researchers included a soluble N component to the BS, initial and intermediate turf responses were improved. When higher BS application rates are used ($\geq$147 kg $ha^{-1}$), turf quality compared favorably with other N sources (Young et al., 1999). Observations from Sartain (1999), Carrow (1997), and Young et al. (1999) indicate turf quality produced from BS is dependent on N application rate, which, in turn, influences the amount of N mineralized and available for plant uptake. Application rates of BS used in the current study (49 kg $ha^{-1}$) were likely too low to maintain an adequate supply of N via mineralization to equal turf quality produced by either soluble or slow-release synthetic N sources.

In 2011, only urea failed to produce St. Augustinegrass growth rates greater than the control. Additionally, the 50% SRN, PCU2, and PCU1 resulted in higher St. Augustinegrass growth rates than most other N sources. Centipedegrass growth rate was increased by each N source compared with the control. The BS produced the lowest growth rate and PCU2 produced the highest at 10.0 and 16.9 kg $ha^{-1}$ $d^{-1}$, respectively. In 2011, ammonium nitrate, urea, PCU1, PCU2, and the control produced unacceptable St. Augustinegrass. The 50% SRN and 30% SRN produced St. Augustinegrass qualities of 7.2 and 6.9, respectively, which were higher than all other N sources except BS. The 50% SRN and 30% SRN were the only treatments to contain both a synthetic, soluble, and SRN component. These results suggest this may be advantageous to turf quality, particularly during the initial months following sodding. Presumably, the soluble component provided sufficient N immediately following fertilization, and the slow-release component provided a gradual release of the remaining N. This likely decreased any incidences of N deficiency and, thus, turf quality was increased.

## CONCLUSIONS

These results indicate N applications to newly sodded turf pose an increased risk to N leaching. Current fertilizer recommendations reflect these findings by limiting N applications to sodded turf until 30 to 60 d after planting (Trenholm et al., 2011). These results indicate increased N leaching due to establishment may continue through 90 d after planting. When turf exhibits symptoms of winterkill or disease, N applications may increase N leaching. Most turf fertility recommendations are predicated on having a healthy, dense turf. These results suggest that N recommendations to turf may need to be revised to include N applications to nonhealthy turf. Nitrogen leaching research, as influenced by cold stress or disease injury, is limited and would be valuable information. Nitrogen leaching was higher from St. Augustinegrass than from centipedegrass. This may not necessarily reflect the differences between the turfgrasses' growth characteristics and associated N uptake potential but rather the differences in their ability to withstand winterkill and large patch. We do not discount the likelihood that differences in turfgrass growth characteristics may play a role in N leaching differences between St. Augustinegrass and centipedegrass. However, in this case, the results indicate that N leaching differences between St. Augustinegrass and centipedegrass did not exist under the normal growing years of 2009 and 2011. On centipedegrass, PCU applied at 98 kg $ha^{-1}$ every 120 d resulted in equal or greater turf quality and growth than PCU at 49 kg $ha^{-1}$ applied every 60 d. Florida BMP recommendations currently restrict the use of slow-release fertilizer to rates $\leq$49 kg $ha^{-1}$. Fertilizer rates $\leq$98 kg $ha^{-1}$ from certain SRN materials may be necessary to utilize the extended slow-release technologies effectively.

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## References


Balkcom, K.S., A.M. Blackmer, D.J. Hansen, T.F. Morris, and A.P. Mallarino. 2003. Testing soils and cornstalks to evaluate nitrogen management on the watershed scale. J. Environ. Qual. 32:1015–1024. doi:10.2134/jeq2003.1015

Barton, L., and T.D. Colmer. 2006. Irrigation and fertiliser strategies for minimising nitrogen leaching from turfgrass. Agr. Water Manage. 80:160–175. doi:10.1016/j.agwat.2005.07.011

Bowman, D.C., C.T. Cherney, and T.W. Rufty. 2002. Fate and transport of nitrogen applied to six warm-season turfgrasses. Crop Sci. 42:833–841. doi:10.2135/cropsci2002.0833

Bowman, D.C., D.A. Devitt, M.C. Engelke, and T.W. Rufty. 1998. Root architecture affects nitrate leaching from bentgrass turf. Crop Sci. 38:1633–1639. doi:10.2135/cropsci1998.0011183X003800060036x

Burpee, L.L. 1995. Interactions among mowing height, nitrogen fertility, and cultivar affect the severity of Rhizoctonia blight of tall fescue. Plant Dis. 79:721–726. doi:10.1094/PD-79-0721

Carrow, R.N. 1997. Turfgrass response to slow-release nitrogen fertilizers. Agron. J. 89:491–496. doi:10.2134/agronj1997.00021962008900030020x

Connell, J.A., D.W. Hancock, R.G. Durham, M.L. Cabrera, and G.H. Harris. 2011. Comparison of enhanced-efficiency nitrogen fertilizers for reducing ammonia loss and improving bermudagrass forage production. Crop Sci. 51:2237–2248. doi:10.2135/cropsci2011.01.0052

Cutulle, M., J. Derr, D. McCall, A. Nichols, and B. Horvath. 2014. Effect of mowing height and fertility on bermudagrass (*Cynodon dactylon*) encroachment and brown patch severity in tall fescue. Weed Technol. 28:225–232. doi:10.1614/WT-D-13-00121.1

Engelsjord, M.E., and B.R. Singh. 1997. Effects of slow-release fertilizers on growth and on uptake and leaching of nutrients in Kentucky bluegrass turfs established on sand-based root zones. Can. J. Plant Sci. 77:433–444. doi:10.4141/P96-034

Erickson, J.E., D.M. Park, J.L. Cisar, G.H. Snyder, and A.L. Wright. 2010. Effects of sod type, irrigation, and fertilization on nitrate-nitrogen and orthophosphate-phosphorus leaching from newly established St. Augustinegrass sod. Crop Sci. 50:1030–1036. doi:10.2135/cropsci2009.07.0411

Exner, M.E., M.E. Burbach, D.G. Watts, R.C. Shearman, and R.F. Spalding. 1991. deep nitrate movement in the unsaturated zone of a simulated urban lawn. J. Environ. Qual. 20:658–662. doi:10.2134/jeq1991.00472425002000030025x

Florida Department of Agriculture and Consumer Services. 2008. Best management practices for Florida sod. Florida Dep. of Agric. and Consumer Serv., Tallahassee, FL.

Florida Department of Environmental Protection. 2010. Florida friendly best management practices for protection of water resources by the green industries. Florida Dep. of Environ. Protection, Tallahassee, FL.

Frank, K.W., K.M. O'Reilly, J.R. Crum, and R.N. Calhoun. 2006. The fate of nitrogen applied to a mature Kentucky bluegrass turf. Crop Sci. 46:209–215. doi:10.2135/cropsci2005.04-0039

Fry, J., and B. Huang. 2004. Applied turfgrass science and physiology. John Wiley, Hoboken, NJ.

Geron, C.A., T.K. Danneberger, S.J. Traina, T.J. Logan, and J.R. Street. 1993. The effects of establishment methods and fertilization practices on nitrate leaching from turfgrass. J. Environ. Qual. 22:119–125. doi:10.2134/jeq1993.00472425002200010015x

Guertal, E.A., and J.A. Howe. 2012. Nitrate, ammonium, and urea leaching in hybrid bermudagrass as affected by nitrogen source. Agron. J. 104:344–352. doi:10.2134/agronj2011.0262

Guillard, K., and K.L. Kopp. 2004. Nitrogen fertilizer form and associated nitrate leaching from cool-season lawn turf. J. Environ. Qual. 33:1822–1827. doi:10.2134/jeq2004.1822

Hochmuth, G., T. Nell, J.B. Unruh, L. Trenholm, and J. Sartain. 2012. Potential unintended consequences associated with urban fertilizer bans in Florida: A scientific review. Horttech. 22:600–616.

Petrovic, A.M. 2004. Nitrogen source and timing impact on nitrate leaching from turf. Acta Hortic. 661:427–432.

Quiroga-Garza, H.M., G.A. Picchioni, and M.D. Remmenga. 2001. Bermudagrass fertilized with slow-release nitrogen sources. I. Nitrogen uptake and potential leaching losses. J. Environ. Qual. 30:440–448. doi:10.2134/jeq2001.302440x

Sartain, J.B. 1999. St. Augustinegrass response to natural organic fertilizers. Turfgrass research in Florida: A technical report. IFAS University of Florida. p. 51–57.

SAS Institute. 2010. SAS/STAT user's guide. Version 9.3. SAS Inst. Inc., Cary, NC.

Snyder, G.H., B.J. Augustin, and J.M. Davidson. 1984. Moisture sensor-controlled irrigation for reducing n leaching in bermudagrass turf. Agron. J. 76:964–969. doi:10.2134/agronj1984.00021962007600060023x

Snyder, G.H., and J.L. Cisar. 2000. Monitoring vadose-zone soil water for reducing nitrogen leaching on golf courses In: Fate and management of turfgrass chemicals. American Chemical Society, Washington, DC. p. 243–254.

Trenholm, L.E., J.L. Cisar, and J.B. Sartain. 2011. St. Augustinegrass for Florida lawns. ENH 5: Http://edis.ifas.ufl.edu/lh010 (accessed 30 Dec. 2014).

Trenholm, L.E., J.B. Unruh, and J.B. Sartain. 2012. Nitrate leaching and turf quality in established 'Floratam' St. Augustinegrass and 'Empire' Zoysiagrass. J. Environ. Qual. 41:793–799. doi:10.2134/jeq2011.0183

Trenholm, L.E., J.B. Unruh, and J.B. Sartain. 2013. Nitrate leaching and turf quality in newly sodded St. Augustinegrass. J. Plant Nutr. 36:1935–1943. doi:10.1080/01904167.2013.819893

USEPA 1983. Nitrogen, nitrate–nitrite. Method 353.2 (colorimetric, automated, cadmium reduction). Methods for chemical analysis of water and wastes, EPA-600/4-79020. USEPA, Cincinnati, OH.

Wu, L.S., R. Green, G. Klein, J.S. Hartin, and D.W. Burger. 2010. Nitrogen source and rate influence on tall fescue quality and nitrate leaching in a Southern California lawn. Agron. J. 102:31–38. doi:10.2134/agronj2009.0209

Young, N.G., J.L. Cisar, J.E. Erickson, G.H. Snyder, J.B. Sartain, and K.E. Williams. 1999. St. Augustinegrass response to nitrogen sources under contrasting application rates and frequency. Int. Turf. Soc. Res. J. 11:121–136.