# Nitrate-N Leaching from 'Floratam' St. Augustinegrass and 'UltimateFlora®' Zoysiagrass During Winter Months

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Abbreviations: Best Management Practices (BMPs), High-density polyethylene (HDPE), minimum detection limit (MDL), nitrate N ($NO_3$–N), nitrogen (N), turf color (TC), turf quality (TQ)

**ABSTRACT**

There are increasing fertilizer regulations restricting timing of lawn fertilizations in Florida. As a result of this, fertilization in many areas is primarily restricted to fall, winter, or spring months, when the grass may not be actively growing. The objectives of this research were to evaluate differences in nitrate-N ($NO_3$–N) mass flux and turfgrass quality from application of nitrogen at different rates throughout the winter months and to look at differences in $NO_3$–N mass flux due to month of application. The research was conducted in Citra, FL from 2006-2009. Nitrogen (N) was applied monthly throughout the winter as soluble urea (46-0-0) at 0, 6.1, 12.2, 24.5, 49.0, or 98.0 kg N $ha^{-1}$ to 'Floratam' St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze.) and 'UltimateFlora®' zoysiagrass (*Zoysia japonica* Steud). There were differences in yrs 1 and 3 in cumulative $NO_3$–N leached due to interactions of grass × N rate. St. Augustinegrass tended to have higher leaching only at the highest N rates, while zoysiagrass leaching increased as N rate increased. Where differences existed due to grass, leaching was greater from zoysiagrass. There were also significant month × grass × N rate interactions. With the exception of the first year when grasses had recently been sodded, greatest leaching typically occurred in the winter and spring months prior to spring green-up rather than in the fall months. Turf quality (TQ) and color (TC) were generally below an acceptable score of 6 for all months in all years, although St. Augustinegrass at highest N rates had some color scores at or just above acceptable. Due to increased potential for $NO_3$–N leaching and little or no improvement to TQ and TC, it is not recommended that lawn grasses be fertilized throughout the winter months, even if fertilization restrictions limit N application during times of active growth.

There are increasing concerns nationwide that fertilizers applied to lawn grasses may result in impairment of ground or surface waters. This has resulted in development of Best Management Practices (BMPs) to reduce nutrient leaching and runoff of fertilizers applied to turf and landscapes. In some areas, ordinances, rules, or regulations regarding fertilization have also been enacted. As an example, a number of local fertilizer ordinances in Florida now regulate timing of fertilizer application. Many of these prohibit turf fertilization during the summer months when grass is most actively growing in an effort to avoid fertilization when chances of heavy precipitation are higher. This restricts fertilization timing to spring, fall, and winter. Depending on geographical location in the state, grasses may be in various states of dormancy throughout much of the winter and spring, which could potentially result in nutrient losses through leaching or runoff.

Fertilizer recommendations for warm-season grasses are typically timed to coincide with active grass growth, particularly where grasses may experience significant winter dormancy. There are few reports documenting $NO_3$–N loading from warm-season grasses during winter months. Brown et al. (1977) reported greatest $NO_3$–N losses in 'Tifdwarf' bermudagrass (*Cynodon dactylon* L. x *C. transvaalensis* Burtt-Davy) during winter months. Leaching losses were associated with high drainage volumes. They further noted that application of organic N sources resulted in lower amounts of $NO_3$–N mass flux, regardless of season of application. They measured a range from 15.5 to 37.8% of applied N leached when N was applied at 98 and 24 kg N $ha^{-1}$, respectively. Snyder et al. (1984) reported greater $NO_3$–N leaching losses from bermudagrass fertilized in winter months than in warmer months.

A stand of Kentucky bluegrass (*Poa pratensis* L.) and creeping red fescue (*Festuca rubra* L.), fertilized at a rate of 49 kg N $ha^{-1}$ from mid-Sept to mid-Dec had increased $NO_3$–N concentration and mass losses in percolate from the later application dates (Mangiafico and Guillard, 2006). The authors concluded that late fall N applications, in combination with increased chance of precipitation at this time, increased the likelihood of potential nutrient leaching or runoff and resulting water impairment. They suggested that cool-season grass fertilization recommendations for fall fertilization be revised due to potential water quality concerns. Similarly, Guillard and Kopp (2004) reported highest $NO_3$–N leaching losses in a mixed sward of cool-season grasses from fertilizer applied in late fall through early spring, particularly when N was applied as a water soluble source.

Kentucky bluegrass had rapid uptake and immobilization of $^{15}N$-labeled urea, regardless of whether the N was applied in a series of spring or fall applications (Miltner et al., 1996). The authors concluded that even late fall N fertilization did not pose a potential threat to groundwater when the turf had high density and organic matter buildup as thatch. Petrovic (2004) reported that late fall N application to Kentucky bluegrass resulted in $NO_3$–N leaching at rates of 29 to 47% of applied N from water soluble N sources, while only 0-12% of the applied N leached when N was applied in a slow release form.

This research was undertaken to observe the effects of 1) N rate and species and 2) month of application on $NO_3$–N loading and TQ due to winter N application to Floratam St. Augustinegrass and UltimateFlora® zoysiagrass.

## MATERIALS AND METHODS

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

Plots measured 4.0m x 4.0m. High-density polyethylene (HDPE) drainage lysimeters were installed in the center of each plot, with the top approximately 10 cm below the soil surface. Lysimeters measured 57 cm diam. and 88 cm in height with a volume of 168 L. Lysimeters were assembled by placing HDPE cylinders into a single piece galvanized steel base unit measuring 25.4 cm in height. A bulkhead fitting was inserted into the base of each unit, to which collection tubing (0.95 cm low density polyethylene) was attached. The tubing was run underground to central aboveground collection portals. Lysimeters were installed by boring and removing soil in 15.2 cm sections to a depth of 107 cm. Lysimeters were placed in holes and bases of the units were filled with washed egg rock (1.9 – 6.4 cm) for a volume of 38 L. The gravel was covered with fitted non-woven polyolefin cloth that was secured with a hoop of 1.3 cm HDPE tubing to reduce soil intrusion into the reservoir. Soil was replaced into the lysimeters as it had been removed from the soil profile. Soil was gently tamped with a tamping tool (17 kg and 858 $cm^2$) to approximate original soil bulk density. Floratam St. Augustinegrass and UltimateFlora® zoysiagrass were sodded in Oct 2006 and allowed to establish for 6 wks prior to treatment application.

Nitrogen treatments were applied monthly beginning in late fall and ending in Mar each of the three yrs. The nitrogen (46-0-0 urea), was dissolved in water and applied through a backpack sprayer to uniformly cover each plot at a rate of 0.12 L $m^{-2}$. Treatments were irrigated in with 1.3 cm of water after application. Monthly application rates were 0, 6.1, 12.2, 24.5, 49.0, or 98.0 kg N $ha^{-1}$.

Turf was mowed as needed throughout the study period, typically an average of twice monthly. Mowing heights were 8.8 and 5 cm, respectively, for St. Augustinegrass and zoysiagrass. Clippings were returned to the ground.

Leachate samples were collected twice weekly throughout the study period in yrs 1 and 2 and weekly in yr 3. Leachate collection began the day after first treatment application and continued until 4-5 wks after last treatment application each yr. Samples were collected by applying a vacuum to the collection tubing and withdrawing percolate from the reservoir of the lysimeter until dry. To prevent a perched water table from forming, lysimeters were evacuated more than twice weekly if heavy rain events (> 2.5 cm) occurred. The large surface area of the lysimeters enhanced percolation through the soil profile, so preferential flow within lysimeters was minimized. Volume was measured by collecting leachate into a graduated cylinder as lysimeters were emptied. Twenty-ml aliquots of the leachate were transferred to collection vials and placed on ice in the field and then frozen at 0° C until $NO_3$–N analysis was done. Nitrate concentration was measured using a continuous segmented flow analyzer (AutoAnalyzer 3, Seal Analytical, Mequon, WI) at the University of Florida Analytical Research Laboratory in Gainesville. In yrs 1 and 2, any concentrations that were lower than a minimum detection limit (MDL) of 0.05 mg $L^{-1}$ were corrected to the MDL value. In yr. 3, the MDL was changed to 0.15 mg $L^{-1}$ and any values below this number were adjusted accordingly.

Turf quality was assessed biweekly over the growing season on a scale of 1 to 9, where 1 = dead or dormant brown turf and 9 = optimal healthy, green turf. A score of 6 was considered a minimally acceptable score for a home lawn.

Weather data were collected from an onsite weather network system (http://fawn.ifas.ufl.edu), which provides meteorological information in 15-min intervals.

Experimental design was a split plot design, where grasses were main plots and N rates were sub plots. Where data were analyzed to determine differences due to month of application and the interaction of month, grass and N rate, a split-split plot design was used.  There were 4 replications. Proc ANOVA and GLM (SAS Institute, 2003) were used to analyze data and means were separated with the Waller Duncan *k*-ratio t-test. Differences were determined at the 0.05 significance level. Due to differences in data between years, results are presented by year. Leachate data were found to be normally distributed and were adjusted for outliers that exceeded plus or minus two standard deviations.

## RESULTS AND DISCUSSION

### Climate

Monthly rainfall totals and average monthly temperatures for the study period for each yr are reported in Table 1. In yr 1, total rainfall exceeded the historical average for Nov-Apr by approximately 9%, while the totals for yrs 2 and 3 were 20 and 57% below average, respectively. Average monthly temperatures did not vary excessively from the historical average for any year.

### Nitrate N Mass Flux

In yr 1, there were differences in cumulative $NO_3$–N mass flux in response to the interaction of grass × N rate (Table 2). In St. Augustinegrass, there were no differences in N mass flux at N rates up to 49.0 kg N $ha^{-1}$, with greatest N loading from application of 98.0 kg N $ha^{-1}$. Zoysiagrass had greatest loading from the two highest N rates. Zoysiagrass had no differences in $NO_3$–N loading between control treatments and up to 12.2 kg N $ha^{-1}$.

In year 2, cumulative $NO_3$–N loads differed in response to main effects of grass and N rate (Table 2). Cumulative loads were 5.2 vs. 14.2 kg N $ha^{-1}$ for St. Augustinegrass and zoysiagrass, respectively. There were no differences in loading from 0 to 49.0 kg N $ha^{-1}$, with greatest loading resulting from application of 98.0 kg N $ha^{-1}$.

In yr 3, cumulative leaching differed due to the interaction of grass × N rate (Table 2). Similar to yr 1 results, loading from St. Augustinegrass was greatest from the highest N application rate, with no differences between the other rates. Highest loads in zoysiagrass occurred at the two highest N rates, with no differences between the lower rates.

Nitrate-N loads were compared for the interaction of grass, N rate, and month of application. In yrs 1 and 3, there were significant 3 way interactions (Table 3). In yr 2, there were differences due to grass and the interaction of N rate × month. In yr 1, St. Augustinegrass had no differences in $NO_3$–N loading between months at the highest N rate (Table 4). At 49.0 kg N $ha^{-1}$, greatest loading occurred Nov-Feb. At the lower rates, loading was greatest in Nov or Nov and Dec at the 6.1 kg N $ha^{-1}$ rate only. In zoysiagrass, greatest N loading at the 4 highest rates rate occurred in Dec, Jan and Mar. At the 6.1 kg N $ha^{-1}$ rate, greatest loading was in Dec.

In yr 2, there were differences between months at the two highest application rates only (Table 5). Lowest $NO_3$–N loading occurred in Dec and Jan at the 98.0 kg N $ha^{-1}$ rate. At the 49.0 kg N $ha^{-1}$ rate, loading was significantly greater in Mar than in Dec.

In yr 3, there were differences in loading from St. Augustinegrass between months at all N rates except for the 49.0 kg N $ha^{-1}$ rate (Table 6). At the highest N rate, loading was greatest in Feb and Mar. At rates of 24.5 and 6.1 kg N $ha^{-1}$, greatest loading occurred in Jan-Mar. At 12.2 kg N $ha^{-1}$, greatest loads occurred Dec-Mar. Zoysiagrass loading was greatest at the two highest N rates in Jan and Feb. At application rates of 12.2 and 24.5 kg N $ha^{-1}$, loading was greatest Jan-Mar and in Feb and Mar at the 6.1 kg N $ha^{-1}$ application rate.

In all yrs, where there were differences due to grass, less $NO_3$–N leached from St. Augustinegrass. For yr 1, cumulative leaching load totaled 15.0 vs. 62.7 kg $ha^{-1}$ from St. Augustinegrass and zoysiagrass, respectively, averaged over N treatments (data not shown). Previous research has similarly reported reduced $NO_3$–N leached from St. Augustinegrass than from other species investigated. Erickson et al. (2001) observed a cumulative annual $NO_3$–N load of 4.1 kg ha$^{-1}$ from St. Augustinegrass compared to 48.3 kg ha$^{-1}$ from a mixed landscape planting. Trenholm et al. (in press) reported average annual mass flux of 1.4 vs. 10.1 and 3.8 vs. 61.2 kg ha$^{-1}$ from St. Augustinegrass and zoysiagrass, respectively, for two subsequent years.

Leaching loads were reduced each subsequent yr in both grasses, from a cumulative total of 15.0 to 4.3 kg ha$^{-1}$ for St. Augustinegrass in yrs 1 and 3, respectively, a decrease of 71% $NO_3$–N loading as the grass matured. In zoysiagrass, levels ranged from 62.7 in yr 1 to 11.4 kg ha$^{-1}$ by yr 3, a decrease of 82%. Reductions in $NO_3$–N leaching loads from turfgrass over sequential years has been reported previously (Easton and Petrovic, 2004) and is often attributed to increased root and shoot growth. Bowman et al. (1998) elucidated the relationship between root architecture and $NO_3$–N leaching in bentgrass (*Agrostis palustris* Huds.), noting that a deeper rooting genotype leached less $NO_3$–N than a shallow rooting genotype. Working with warm-season species, Bowman et al. (2002) found that root length density was negatively correlated with $NO_3$–N losses. In addition to increased grass maturity, reduced leaching loads in yrs 2 and 3 may be attributed in part to reduced rainfall during the study period in those yrs. Higher than average rainfall occurred in yr 1 from Nov – Apr, while rainfall totals were reduced in the following yrs. Brown et al (1977) found higher potential for increased $NO_3$–N loads during times of high rainfall and low plant water use in bermudagrass.

In yr 1, greatest loading in St. Augustinegrass occurred in the fall and early winter months, when treatments were applied 6 wks after grass was planted. This may be attributed to nutrient import from the freshly harvested sod and the lack of a root system.

In zoysiagrass, the trend was reversed, with greatest loading in the winter and spring months. In yrs 2 and 3, both grasses had greatest loading in winter and spring months.

Greater $NO_3$–N flux in winter and spring is most likely due to two factors, the first being climatic conditions. In yr 2, the winter was mild, with above average rainfall in Feb and Mar, when leaching was accelerated at the highest N rates. Year 3, when lowest $NO_3$–N loading occurred, had lower than average rainfall and temperatures that were close to historical averages over the entire study period. The second contributing factor is likely directly related to root growth characteristics of warm season grasses in winter months. Seasonal dynamics of warm-season turfgrass rooting is poorly understood with few published results. Sifers et al., (1985) reported that root growth of 'Tifgreen' bermudagrass and Floratam St. Augustinegrass continued after shoot growth had ceased and after low temperature shoot discoloration and conditional winter dormancy had occurred. Wherley et al, (2009) found that dormant bermudagrass was inefficient (≤ 10 – 20% recovery) at filtering $^{15}N\text{-}NO_3^-$ from effluent water. However, they found that 80 – 90% of $^{15}N\text{-}NO_3^-$ was assimilated within 1 wk during spring and fall transition months. Our observed lower fluxes in the fall and early winter months may be attributed to functioning root systems even though the grasses were in varying states of dormancy.

Sifers et al., (1985) also reported that warm-season turfgrasses undergo spring root decline (i.e., severe browning of the entire root system) just after spring green-up. They noted that a 2 – 3 wk period exists when functional capabilities (e.g., nutrient uptake) of the grass root system were several restricted. Turf quality and TC data (Tables 7 – 9) reveal a downward trend during the months of Dec and Jan, reaching their lowest ratings in Feb followed by an upward trend (i.e., spring green-up) between Feb and Mar.

We surmise that spring root decline during this period could be possible and this may be contributing to greater $NO_3$–N leaching.

The results from monthly flux analysis suggest that in an established warm-season grass, late fall N application is preferable to winter or early spring fertilization for reduction of $NO_3$–N loading. This may be an important management practice for reduction of $NO_3$–N loading where ordinances or regulations prohibit N fertilization throughout the growing season**.**

## Turf Quality and Color

Turf quality scores differed due to the interaction of grass × N rate in yr 1 in Dec, Jan and Mar (Table 7). St. Augustinegrass had increased quality in response to N from Dec-Mar, although scores were largely below acceptable from Jan-Mar. Turf quality in zoysiagrass was less responsive to N rate and quality scores were below acceptable from Jan-Mar. There was an interaction of grass × N rate for color scores in yr 1 in Nov and Mar and differences due to main effects of both grass and N rate in the other months. Color scores were below acceptable at all treatment levels in both grasses for each month, with the exception of St. Augustinegrass in Dec that received N at rates > 12.2 kg N $ha^{-1}$.

In yr 2, TQ had minor differences due to grass and N rate, with increased TQ as N increased in both grasses in Dec and Jan (Table 8). Quality scores for both grasses were below acceptable in all months. Color scores responded to the interaction of N × grass in all months in yr 2. Color scores were less than acceptable, with the exception of St. Augustinegrass at the highest N rate in Jan and Feb and N at 24.5 kg N $ha^{-1}$or greater in Mar.

Turf quality was below acceptable at all ratings in yr 3 for both grasses, with grass × N interactions in Nov, Dec and Jan (Table 9). Color scores differed in response to the interaction of grass × N in all months except for Mar. Scores were below acceptable, with the exception of St. Augustinegrass in Nov at the two highest N rates.

While application of the higher rates of N tested in this study provided some enhancement of TQ and TC during some months, it was difficult to reach acceptable TQ and TC scores even at the highest N rates.

## CONCLUSIONS

Application of low rates (< 24.5 kg N $ha^{-1}$) of N during winter months to St. Augustinegrass or zoysiagrass did not result in $NO_3$–N fluxes greater than those of control plots, but also did not enhance TQ or TC. At higher N rates, greater $NO_3$–N loading was likely and, while TQ and TC may have increased slightly, in 2 of the 3 yrs, TQ and TC were below acceptable quality at any N rate. Additionally, the high rates would result in N application in excess of the currently recommended N rates (Sartain, 2007). There was a trend towards greater $NO_3$–N leaching in the winter and early spring months prior to spring green-up, a time when commercial lawn care services are often beginning annual lawn maintenance services. If an additional N application were needed due to contractual obligations or due to summer fertilizer restrictions, these results suggest that N application in the late fall months would be preferable to winter or early spring application to reduce the potential for $NO_3$–N mass loading.

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Table 1. Climatology and average historical data for the periods during which the research was conducted from 2006 to 2009 in Citra, Fl.

| Rainfall | 2006-07 | 2007-08 | 2008-09 | Average |
|---|---|---|---|---|
| | ----------mm---------- | | | |
| Nov | 47.0 | 1.6 | 13.7 | 54.0 |
| Dec | 93.0 | 47.2 | 17.8 | 63.4 |
| Jan | 60.2 | 79.8 | 54.4 | 71.3 |
| Feb | 175.5 | 121.2 | 34.0 | 85.0 |
| Mar | 54.4 | 107.4 | 42.4 | 93.2 |
| Apr | 62.7 | 6.3 | 31.0 | 83.7 |
| Total | 492.8 | 363.5 | 193.3 | 450.6 |
| Temperature | ----------ºC---------- | | | |
| Nov | 16.1 | 16.5 | 15.8 | 18.4 |
| Dec | 16.7 | 16.4 | 16.4 | 17.8 |
| Jan | 14.9 | 13.6 | 13.4 | 15.8 |
| Feb | 13.8 | 15.9 | 13.8 | 12.8 |
| Mar | 17.9 | 17.3 | 17.8 | 18.0 |
| Apr | 19.4 | 20.2 | 20.1 | 19.1 |

Table 2. Analysis of variance and means for $NO_3$–N mass flux in response to N rate during winter months in St. Augustinegrass and zoysiagrass over a 3-yr trial in Citra, FL.

| Grass | Monthly N rate | Cumulative Nitrate N Mass Flux | | |
|---|---|---|---|---|
| | | ----------------------kg N ha$^{-1}$--------------------------- | | |
| | ------kg N ha$^{-1}$--- | Year 1 | Year 2 | Year 3 |
| St. Augustinegrass | | | | |
| | 98.0 | 45.5 a | | 18.7 a |
| | 49.0 | 17.0 b | | 2.8 b |
| | 24.5 | 8.0 b | | 0.9 b |
| | 12.2 | 8.3 b | | 1.4 b |
| | 6.1 | 6.1 b | | 0.9 b |
| | 0 | 5.0 b | | 1.0 b |
| Zoysiagrass | | | | |
| | 98.0 | 113.7 a | | 29.3 a |
| | 49.0 | 107.7 a | | 27.2 a |
| | 24.5 | 53.5 b | | 3.7 b |
| | 12.2 | 42.2 bc | | 3.7 b |
| | 6.1 | 36.8 bc | | 2.0 b |
| | 0 | 22.5 c | | 2.7 b |
| St. Augustinegrass | | | 5.2 b | |
| Zoysiagrass | | | 14.2 a | |
| | 98.0 | | 30.2 a | |
| | 49.0 | | 14.0 b | |
| | 24.5 | | 4.9 b | |
| | 12.2 | | 3.3 b | |
| | 6.1 | | 3.0 b | |
| | 0 | | 2.7 b | |
| ANOVA | | | | |
| Grass (G) | | ** | * | * |
| Nitrogen (N) | | *** | *** | *** |
| G x N | | ** | NS | ** |

Table 3. Analysis of variance for $NO_3$–N mass flux in response to grass, N rate and month of application over a 3-yr trial in Citra, FL.

| ANOVA | Year 1 | Year 2 | Year 3 |
|---|---|---|---|
| Grass (G) | ** | * | * |
| Nitrogen (N) | *** | *** | *** |
| Month (M) | *** | *** | *** |
| G x N | ** | NS | ** |
| G x M | *** | NS | ** |
| N x M | *** | *** | *** |
| G x N x M | *** | NS | ** |

Table 4. Nitrate-N mass flux in response to nitrogen rate and month in yr 1 in St. Augustinegrass and zoysiagrass in Citra, FL.

| | Nitrate N Mass Flux | | | | | |
|---|---|---|---|---|---|---|
| | ---kg N $ha^{-1}$--- | | | | | |
| | 0 | 6.1 | 12.2 | 24.5 | 49.0 | 98.0 |
| Month | St. Augustinegrass | | | | | |
| Nov 06 | 2.7 a | 2.9 a | 4.0 a | 3.8 a | 5.6 a | 5.1 |
| Dec 06 | 1.2 b | 1.4 ab | 1.7 b | 1.6 b | 4.4 ab | 10.2 |
| Jan 07 | 0.7 b | 0.9 b | 1.4 b | 0.7 b | 1.6 ab | 13.4 |
| Feb 07 | 0.3 b | 0.5 b | 0.5 b | 1.2 b | 5.3 a | 12.7 |
| Mar 07 | 0.2 b | 0.3 b | 0.7 b | 0.7 b | 0.1 b | 4.2 |
| | Zoysiagrass | | | | | |
| Nov 06 | 4.4 ab | 5.9 c | 6.7 bc | 6.8 b | 7.7 c | 7.5 b |
| Dec 06 | 5.4 a | 10.8 a | 10.8 ab | 12.9 a | 23.4 ab | 21.9 ab |
| Jan 07 | 4.6 a | 7.8 b | 7.8 a-c | 12.7 a | 30.8 a | 35.6 a |
| Feb 07 | 3.1 b | 4.0 c | 5.1 c | 6.9 b | 12.1 bc | 12.6 b |
| Mar 07 | 4.9 a | 8.3 b | 11.8 a | 14.3 a | 33.7 a | 36.1 a |

Table 5. Nitrate-N mass flux in response to nitrogen rate and month in yr 2 in St. Augustinegrass and zoysiagrass in Citra, FL.

| | Nitrate N Mass Flux | | | | | |
|---|---|---|---|---|---|---|
| | --kg N ha$^{-1}$-- | | | | | |
| Month | 0 | 6.1 | 12.2 | 24.5 | 49.0 | 98.0 |
| Dec 07 | 0.6 | 0.7 | 0.6 | 0.8 | 0.6 b | 1.0 c |
| Jan 08 | 0.8 | 0.5 | 0.7 | 1.2 | 2.8 ab | 3.7 bc |
| Feb 08 | 0.5 | 0.7 | 0.6 | 0.9 | 3.9 ab | 9.8 ab |
| Mar 08 | 0.8 | 1.1 | 1.4 | 2.0 | 6.6 a | 15.8 a |

Table 6. Nitrate-N mass flux in response to nitrogen rate and month in yr 3 in St. Augustinegrass and zoysiagrass in Citra, FL.

| | Nitrate N Mass Flux | | | | | |
|---|---|---|---|---|---|---|
| | --------kg N $ha^{-1}$-------- | | | | | |
| | 0 | 6.1 | 12.2 | 24.5 | 49.0 | 98.0 |
| Month | St. Augustinegrass | | | | | |
| Nov 08 | 0.04 c | 0.04 c | 0.05 b | 0.03 b | 0.1 | 0.04 b |
| Dec 08 | 0.1 c | 0.1 bc | 0.1 ab | 0.1 b | 0.1 | 0.1 b |
| Jan 09 | 0.2 b | 0.3 a | 0.6 a | 0.3 a | 0.5 | 2.7 b |
| Feb 09 | 0.2 b | 0.2 ab | 0.4 ab | 0.3 a | 1.6 | 11.0 a |
| Mar 09 | 0.4 a | 0.3 a | 0.3 ab | 0.1 ab | 0.5 | 4.9 ab |
| | Zoysiagrass | | | | | |
| Nov 08 | 0.2 | 0.1 cd | 0.2 b | 0.2 b | 0.1 c | 0.3 c |
| Dec 08 | 0.3 | 0.1 d | 0.1 b | 0.3 b | 0.2 c | 0.3 c |
| Jan 09 | 0.9 | 0.4 bc | 1.0 ab | 1.4 a | 9.1 b | 7.2 b |
| Feb 09 | 0.5 | 0.5 ab | 0.8 ab | 0.8 ab | 14.2 a | 15.0 a |
| Mar 09 | 0.7 | 0.7 a | 0.9 ab | 0.9 ab | 3.6 c | 6.2 bc |

Table 7. Average turf quality and color of St. Augustinegrass and zoysiagrass in response to nitrogen rate in yr 1 (2006-07) in Citra, FL. Turf quality was based on a scale of 1 to 9, where 1 = dead, brown turf and 9 = optimal healthy, green turf.

| | Monthly N Rate | Turf quality | | | | | Turf color | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| St. Augustinegrass | ---kg N ha$^{-1}$-- | Nov | Dec | Jan | Feb | Mar | Nov | Dec | Jan | Feb | Mar |
| | 98.0 | 6.5 | 7.5 a | 5.3 a | 3.6 a | 6.0 a | 5.9 | 7.6 a | 5.1 a | 2.9 a | 5.6 a |
| | 49.0 | 6.5 | 7.2 b | 5.0 b | 3.2 ab | 5.5 b | 5.7 | 7.0 b | 4.6 b | 2.3 ab | 5.2 ab |
| | 24.5 | 6.5 | 6.6 c | 4.8 c | 2.8 bc | 5.4 bc | 5.7 | 6.4 c | 4.2 bc | 2.0 bc | 4.9 bc |
| | 12.2 | 6.5 | 6.5 c | 4.7 c | 2.4 cd | 5.1 c | 5.7 | 6.1 d | 4.1 c | 1.6 cd | 4.6 cd |
| | 6.1 | 6.5 | 6.5 c | 4.4 d | 2.6 bc | 4.6 d | 5.6 | 5.9 d | 3.6 d | 1.9 bc | 4.3 d |
| | 0 | 6.5 | 6.2 d | 3.8 e | 2.0 d | 4.1 e | 5.1 | 5.4 e | 2.8 e | 1.2 d | 3.6 e |
| Zoysiagrass | | | | | | | | | | | |
| | 98.0 | 6.5 | 6.5 | 4.1 a | 2.1 a | 4.4 a | 4.0 | 4.8 a | 3.1 a | 1.2 a | 3.8 ab |
| | 49.0 | 6.5 | 6.5 | 3.9 ab | 1.9 ab | 4.4 a | 4.0 | 4.6 a | 2.8 ab | 1.1 ab | 3.9 ab |
| | 24.5 | 6.5 | 6.4 | 3.9 ab | 1.9 a-c | 4.4 a | 4.0 | 4.4 ab | 2.8 ab | 1.0 b | 4.0 a |
| | 12.2 | 6.5 | 6.5 | 4.0 a | 1.9 a-c | 4.2 ab | 4.0 | 4.3 ab | 2.6 ab | 1.0 b | 3.5 ab |
| | 6.1 | 6.5 | 6.5 | 3.6 bc | 1.7 bc | 3.9 b | 4.0 | 3.9 ab | 2.1 bc | 1.0 b | 3.4 b |
| | 0 | 6.5 | 6.4 | 3.4 c | 1.6 c | 3.4 c | 4.0 | 3.4 b | 1.6 c | 1.0 b | 2.9 c |
| ANOVA | | | | | | | | | | | |
| Grass (G) | | NS | ** | ** | * | * | *** | ** | ** | ** | NS |
| N Rate (N) | | NS | *** | *** | *** | *** | * | *** | *** | *** | *** |
| G × N | | NS | *** | ** | NS | * | * | NS | NS | NS | * |

Table 8. Average turf quality and color of St. Augustinegrass and zoysiagrass in response to nitrogen rate (N rate) in yr 2 (2007-08) in Citra, FL. Turf quality was based on a scale of 1 to 9, where 1 = dead, brown turf and 9 = optimal healthy, green turf.

| | Monthly N Rate | Turf quality | | | | Turf color | | | |
|---|---|---|---|---|---|---|---|---|---|
| St. Augustinegrass | ----kg N $ha^{-1}$---- | Dec | Jan | Feb | Mar | Dec | Jan | Feb | Mar |
| | 98.0 | 5.8 a | 5.5 a | 4.7 | 5.5 | 5.6 a | 6.0 a | 6.4 a | 6.5 a |
| | 49.0 | 5.5 b | 5.2 b | 4.6 | 5.5 | 5.4 a | 5.6 ab | 5.9 ab | 6.3 a |
| | 24.5 | 5.2 c | 5.0 c | 4.7 | 5.3 | 4.9 b | 5.3 bc | 5.0 bc | 6.0 b |
| | 12.2 | 5.0 cd | 4.9 c | 5.0 | 5.4 | 4.7 bc | 4.9 cd | 4.9 c | 5.5 b |
| | 6.1 | 4.9 cd | 4.8 cd | 4.6 | 4.9 | 4.6 bc | 4.8 cd | 4.3 c | 5.2 b |
| | 0 | 4.8 d | 4.6 d | 4.5 | 4.8 | 4.4 c | 4.5 d | 4.0 c | 5.1 b |
| Zoysiagrass | | | | | | | | | |
| | 98.0 | 5.7 a | 5.0 a | 4.2 | 4.0 | 4.6 a | 4.7 a | 4.9 a | 4.3 ab |
| | 49.0 | 5.7 a | 4.9 ab | 4.6 | 4.4 | 4.4 b | 4.6 ab | 4.8 a | 4.6 ab |
| | 24.5 | 5.5 ab | 4.8 ab | 4.7 | 4.7 | 4.3 bc | 4.6 ab | 4.6 a | 5.0 a |
| | 12.2 | 5.3 bc | 4.7 b | 4.7 | 4.6 | 4.2 cd | 4.4 ab | 4.6 a | 4.9 a |
| | 6.1 | 5.1 cd | 4.7 b | 4.6 | 4.6 | 4.1 d | 4.3 b | 4.4 ab | 4.7 ab |
| | 0 | 4.9 d | 4.5 c | 4.3 | 4.3 | 3.9 e | 4.0 c | 3.6 b | 4.1 b |
| ANOVA | | | | | | | | | |
| Grass (G) | | NS | ** | NS | ** | *** | ** | * | ** |
| N Rate (N) | | *** | *** | NS | NS | *** | *** | *** | ** |
| G × N | | NS | NS | NS | NS | ** | * | * | ** |

Table 9. Average turf quality and color of St. Augustinegrass and zoysiagrass in response to nitrogen rate (N rate) in yr 3 (2008-09) in Citra, FL. Turf quality was based on a scale of 1 to 9, where 1 = dead, brown turf and 9 = optimal healthy, green turf.

| | Monthly N Rate | Turf quality | | | | | Turf color | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| St. Augustinegrass | --kg N $ha^{-1}$-- | Nov | Dec | Jan | Feb | Mar | Nov | Dec | Jan | Feb | Mar |
| | 98.0 | 5.9 a | 5.4 a | 4.3 a | 3.0 a | 5.2 a | 6.6 a | 5.0 a | 3.9 a | 3.1 a | 5.3 a |
| | 49.0 | 5.3 ab | 4.8 ab | 3.9 b | 2.6 a | 4.4 a | 6.1 ab | 4.6 ab | 3.3 ab | 2.3 b | 4.8 a |
| | 24.5 | 4.5 b | 3.9 bc | 2.8 c | 1.8 b | 2.9 b | 5.1 bc | 3.5 cd | 2.3 c | 1.6 c | 3.4 b |
| | 12.2 | 4.3 bc | 3.4 cd | 2.2 d | 1.4 b | 2.4 bc | 5.0 bc | 3.9 bc | 2.5 bc | 1.4 cd | 2.8 bc |
| | 6.1 | 3.1 d | 2.6 d | 2.1 d | 1.6 b | 2.2 bc | 3.3 d | 2.6 d | 2.0 c | 1.1 d | 2.4 cd |
| | 0 | 3.3 cd | 2.6 d | 1.8 e | 1.1 b | 1.5 c | 3.8 cd | 2.8 d | 1.9 c | 1.4 cd | 1.8 d |
| Zoysiagrass | | | | | | | | | | | |
| | 98.0 | 5.6 a | 4.5 a | 3.4 a | 3.5 a | 5.1 a | 5.0 a | 3.8 ab | 2.8 ab | 1.9 a | 5.3 a |
| | 49.0 | 5.4 a | 4.5 a | 3.4 a | 3.5 a | 5.1 a | 5.1 a | 4.0 a | 2.9 a | 1.9 a | 5.1 a |
| | 24.5 | 5.3 ab | 4.0 b | 3.0 b | 3.0 b | 3.6 b | 5.1 a | 3.6 bc | 2.8 ab | 1.8 ab | 3.7 b |
| | 12.2 | 5.1 ab | 3.8 b | 2.9 bc | 2.5 c | 2.9 c | 4.3 b | 3.3 c | 2.5 ab | 1.5 a-c | 3.1 c |
| | 6.1 | 4.6 bc | 3.6 bc | 2.8 bc | 2.4 c | 2.8 c | 4.3 b | 3.5 bc | 2.4 b | 1.4 bc | 2.8 c |
| | 0 | 4.3 c | 3.3 c | 2.6 c | 1.6 d | 2.2 d | 3.8 c | 2.8 d | 1.9 c | 1.1 c | 2.0 d |
| ANOVA | | | | | | | | | | | |
| Grass (G) | | ** | NS | NS | *** | * | NS | NS | NS | NS | NS |
| N Rate (N) | | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| G × N | | * | * | *** | NS | NS | * | ** | ** | *** | NS |