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Influence of Soil Type on Nitrogen Leaching of Controlled Release Fertilizers

Austin L. Grimshaw[1], Brian M. Schwartz[1]*, Tim L. Grey[1], Alec R. Kowalewski[2], and Paul L. Raymer[3]

[1]*Dept. of Crop & Soil Sciences, University of Georgia, 115 Coastal Way, Tifton, GA 31793*

[2]*Dept. of Horticulture, 4017 Agriculture and Life Sciences Building, Oregon State University, Corvallis, OR 97331*

[3]*Dept. of Crop & Soil Sciences, University of Georgia, 1109 Experiment St, Griffin, GA 30223*

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Misuse of nitrogen fertilizers has become an ever increasing problem in management of turfgrass lawns and fields. The environmental impacts of these practices are especially evident in sandy soils that are low in organic matter which can bind nitrogen, or in new turfgrass systems that have not developed mature root systems which are capable of nutrient uptake before leaching occurs. Controlled and slow release fertilizers are designed to release nitrogen over a longer period of time which should improve the efficiency of nitrogen use and reduce leaching. A lysimeter study was performed at the University of Georgia to determine if an experimental fertilizer (E 15-0-0) would reduce leaching compared to UMAXX (47-0-0) and an analog fertilizer (16-4-8). Soil retained nitrate-nitrogen (NO_3-N) and ammonium-nitrogen (NH_4-N) samples were collected from a USGA green's mix, Florida soil, and Maryland soil. The experimental fertilizer leached more NO_3-N than the other fertilizer types in all soils. The analog fertilizer leached more NH_4-N during both trial years in the Florida and USGA soils. Developing an improved controlled release fertilizer would decrease the likelihood of leached nutrients. Further study should be performed in the field to more accurately simulate real world conditions that affect fertilizer application and fate to effectively evaluate nitrogen loss characteristics of these fertilizers.

Interest from both the public sector and various political groups has grown in recent years regarding the contamination of water resources in the United States. Prior to this concern, consumer expectations for turfgrass quality and performance in home lawns and landscapes began to rise, leading to greater fertilizer use and water consumption (Osmond and Hardy, 2004). Turfgrass landscapes have been targeted by environmental agencies as a point source of water contamination due to the use and possible runoff or leaching of nitrogen fertilizers (Duncan and Carrow, 2000). This issue is most prevalent in areas such as the Coastal Plains of the United States that have sandy soils, which are prone to leaching due to basic soil dynamics and their lower water holding capacity (Wang and Alva, 1996). The issue of groundwater contamination is further amplified as microbes in the soil break down ammonium (NH_4-N) into nitrate (NO_3-N), a negatively charged particle that is more easily flushed out of a soil system during water infiltration due to reduced affinity with the soil (Wolkowski, 1995).

Nitrate (NO_3-N) from turfgrass fertilization is one of the proposed sources of groundwater contamination, but researchers have hypothesized that turfgrass can reduce groundwater contamination by reducing runoff and erosion, while promoting metabolism of chemicals before they infiltrate the soil (Erickson et al. 2001). Research has demonstrated that improper irrigation and fertilization, specifically the over-use of quick release fertilizers on turfgrass systems, can lead to excess leaching and groundwater contamination (Petrovic, 1990). To combat this occurrence, researchers have focused on developing best management practices that mitigate the improper use of inputs (Dietz et al., 2004).

*Corresponding author; phone: (229) 386-3272; email: tifturf@uga.edu

Fertilizer developers have improved slow and controlled release fertilizers to combat the issues of water contamination as awareness has increased. These fertilizers use less labor resources and were first developed to reduce the dependence on quick release fertilizers that required a shorter interval between applications (Robbins, 2005). As an added benefit, slow and controlled release fertilizers also were shown to reduce nitrogen leaching (Killian, 1966). Brown et al. (1982) found that NO_3-N levels leached from golf course greens dropped from 8.6%–21.9% to 0.2%–1.6% when slow-release sources such as isobutylidene diurea and ureaformaldehyde were used instead of ammonium nitrate.

Both field and greenhouse methodologies have been developed to collect and quantify nitrogen which has been leached from a soil/root system. Lysimeters of varying sizes have primarily been used in these methodologies. Some studies have used pots with holes drilled in the sides (Saha et al., 2007), while others have used polyvinyl chloride (PVC) pipes (Grey et al., 2009). Additionally, water samples from underground basins have been collected in the field (Erickson et al., 2008), and from drains under golf course greens (Lisi et al., 2004).

Fertilizer companies have a growing interest in developing environmentally friendly products that meet the expectation of public and private stakeholder groups. The objective of this research was to conduct a greenhouse lysimeter nitrogen leaching study to evaluate the possible improved nitrogen leaching potential of an experimental (E 15-0-0) and proprietary (UMAXX) 47-0-0 controlled release fertilizers versus a generic (analog) 16-4-8 granular fertilizer in three growing mediums: Florida soil, Chesapeake Bay Maryland soil, and a United States Golf Association (USGA) specified root zone mix.

Table 1. Soil type composition of three soils prior to nitrogen leaching studies conducted at the University of Georgia during 2011 and 2012.

			mg·kg-1						
Soil Name	Soil Type	pH	Ca	K	Mg	Mn	P	Zn	NO_3-N
USGA	Sand	6.43	64.1	7.01	24.78	1.78	2.02	0.95	0.93
Maryland	Sandy Loam	4.30	257.0	44.5	71.87	5.20	20.96	1.93	28.08
Florida	Sand	4.27	24.6	5.22	6.50	<0.05	6.57	0.79	1.29

Table 2. Soil mineral concentrations of three soils prior to nitrogen leaching studies conducted at the University of Georgia during 2011 and 2012.

		%				
Soil Name	Soil Type	Sand	Silt	Clay	N	OM[3]
USGA	Sand	95.90	2.1	2.0	0.009	0.80
Maryland	Sandy Loam	69.90	18.0	12.1	0.062	1.80
Florida	Sand	89.80	8.2	2.0	0.013	0.80

Materials and Methods

Experimental Design. Nitrogen leaching characteristics of three fertilizers, an experimental controlled release fertilizer (E 15-0-0), a proprietary controlled release fertilizer (UMAXX) 47-0-0 (Urea nitrogen stabilized by dicyandiamide and N-(n-butyl) thiophosphoric triamide) (AGROTAIN International, L.L.C., St. Louis, MO), and a generic fertilizer (analog) 16-4-8 (10.3% ammonical nitrogen, 5.7% urea nitrogen) were studied in comparison to an unfertilized control during two greenhouse trials at the University of Georgia, Griffin and Athens campuses. Trial one was performed between 22 July 2011 and 26 Aug. 2011, and trial two between 6 Mar. 2012 and 17 Apr. 2012. Lysimeters were used to study leachate contents collected from three soils: 1) a (Florida) Immokalee fine sand (sandy, siliceous, hypothermic Aremic Alaquods); 2) a (Maryland) Annapolis sandy loam (fine-loamy, glauconitic, mesic Typic Hapludults); and 3) a (USGA) green's mix which has maximum 10% coarse sand, a minimum of 60% medium, maximum 20% fine sand particles, and no more than 5% silt and 3% clay (Tables 1 and 2). The experimental design was a 4 x 3 factorial, with the three fertilizer treatments and soil types organized in a randomized complete block with two replications (Table 3).

Leachate Collection and Analysis. The lysimeter columns were 10.2 cm x 30.5 cm (4 inch x 12 inch) design, with a funneling cap on the bottom made from polyvinyl chloride (PVC). Leachate was funneled using rubber tubing into 750 ml (25.4 oz.) bottles placed below the racks holding the lysimeters. Each of the three soils was added to the lysimeters to obtain a bulk density of 1.4 to 1.5 $g \cdot cm^{-3}$ for consistency by compacting as they were filled. The field capacity of each lysimeter was determined prior to the experiments by calculating the difference in weight between each when completely dry, and after they had been allowed to drain for 24 h following an irrigation event that brought soil water to field capacity. Kentucky Bluegrass (*Poa pratensis* L.) 'Everest' was seeded (14.5 $g \cdot m^{-2}$ or 0.003 lb ft^2) and allowed to reach 70% coverage before initiation of fertilizer treatments, and was maintained at a height of 7.6 cm (3 inches) by clipping every three days. The four fertilizer treatments were applied at 4.9 $g \cdot m^{-2}$ of N (0.001 lb ft^2) every week for six consecutive weeks. All treatments were applied using 100 ml (3.38 oz) of water as a carrier to uniformly distribute over the entire lysimeter surface. Irrigation was applied daily to the lysimeters to maintain plant health at field capacity in the columns by applying water until a small amount (3-5 ml, 0.1-0.17 oz) of water leached from the bottom of the column, any leachate volume that occurred during the week was recorded before disposal. Irrigation was applied to each column every 7 d until 250 ml (8.45 oz) of leachate was recovered. Two 125 ml (4.23 oz) high-density polyethylene (HDPE) amber bottles (Thermo Fisher Scientific, MA) were filled with the leachate from each column and frozen at –4 °C (24.8 °F) for no longer than 21 d. One leachate sample was tested for nitrogen content, including (NO_3–N) and (NH_4-N) while the second was held in reserve in cold storage at –20 °C (–4 °F). Analysis was performed at the University of Georgia Soil, Plant, and Water Analysis Laboratory, Athens, GA, using a Vernier ion-selective electrode with a minimum detection limit of 0.1 $mg \cdot L^{-1}$. Milligrams of nitrogen in the leachate were determined by converting the parts per million (ppm) level of each sample based on the amount of water recovered per column during that week for the leachate data.

Table 3. Mean squares for nitrate nitrogen (NO_3-N) measured in greenhouse leaching trials performed at the University of Georgia in Griffin, GA and Athens, GA during 2011 and 2012.

		Mean squares			
Source	df	NO_3-N Leachate	NH_4-N Leachate	NO_3-N Soil	NH_4-N Soil
Trial	1	1449	19270^z	194^z	652^z
Error a, Rep(Trial)	2	194	68	0.2	0.8
Soil	2	28925^z	14127^z	26^z	692^z
Treatment	3	23714^z	12986^z	85^z	260^z
Soil x Trial	2	437	5478^z	3	444^z
Treatment x Trial	3	606	7101^z	86^z	86^z
Treatment x Soil	6	4186^z	3265^z	10^y	198^z
Treatment x Trial x Soil	6	144	1933^z	6	77^z
Error b	22	1007	89	3	5

^{z}Significant at $P = 0.01$.
^{y}Significant at $P = 0.05$.

Statistical Analysis. The distribution of data for cumulative (NO_3-N) and (NH_4-N) recovered in the leachate over the course of the six-week experiment was assessed with a histogram and normal probability plot for normality. An analysis of variance was performed on each of the measured traits to test whether fertilizer treatments and soil types varied (Table 3). Fertilizer treatments and soil types were separated using a Fisher's least significant difference (LSD) at the 0.05 level of probability.

Results and Discussion

Cumulative Leachate Nitrate-Nitrogen (NO_3-N) and Ammonium-Nitrogen (NH_4-N)

Leachate collected weekly throughout the study was analyzed for differences at each sampling date for effects due to fertilizer source in each of the three soils to access the amount of nitrogen lost from each lysimeter (data not shown). Results are reported as a cumulative six week total for the experiment. In the overall analysis of variance for NO_3-N (Table 3), soil and treatments were significant at ($P \leq 0.01$). Trial interactions were not significant, thus results are combined for the two years.

Soils responded differently ($P \leq 0.01$) in the amount of leachate collected based on the treatments; in all cases the mean NO_3-N leachate from the E 15-0-0 treatment was the greatest but was not significant in the Maryland sandy loam soil (Fig. 1). In the Florida soil, fertilizing with the E 15-0-0 resulted in leachate containing a total of 34.4 mg NO_3–N, approximately seven times that found in the leachate collected from lysimeters fertilized with the analog (4.8mg NO_3-N) and UMAXX (4.6mg NO_3-N) products, which were not statistically different from the amount of NO_3-N found in the unfertilized control (1.4mg). The overall leachate collections of NO_3-N in the USGA sand were higher than found in the Florida sand and may be explained by the higher percentages of smaller particles (8.2% silt, 2% clay) (Table 2) in the Florida sand soil. A higher concentration of silt and clay has been shown to be correlated with reduced NO_3-N concentrations in leachate from different sources of nitrogen (Guertal and Howe, 2012). The highest losses of NO_3-N were found in leachate collected from the E 15-0-0 treatment (120.8 mg NO_3-N), followed by UMAXX (44.1 mg NO_3-N), analog (25.2 mg NO_3-N), and the unfertilized control (2.8 mg NO_3-N). Leachate from the Maryland sandy loam soil contained the highest mean concentrations of NO_3-N of the three soils, although variability prevented statistical separation from the other fertilizer treatments. The Maryland sandy loam soil was composed of 18% silt, 12.1% clay and more than double the organic matter of either the Florida sand or USGA sand (Table 2). Strictly judged on soil classification and organic matter content, the Maryland sandy loam soil should have a greater ability to prevent leaching. However, the initial soil analysis of the Maryland sandy loam soil indicated it contained 28.08 $mg \cdot kg^{-1}$ of NO_3–N as opposed to 0.93 $mg \cdot kg^{-1}$ and 1.29 $mg \cdot kg^{-1}$ of NO_3–N in the USGA sand and Florida sand soils, respectively (Table 1). The initial NO_3-N level may have been high enough to saturate the CEC of the Maryland sandy loam soil, thereby minimizing the possibility for soil binding to occur when fertilizer was applied, which would allow the flushing of NO_3-N particles in a leaching event.

For leached NH_4-N (Fig. 2), all interactions were significant at $P \leq 0.01$ (Table 3), thus results are reported separately for soil types and trials conducted in 2011 and 2012. Generally, the results for NH_4-N leachate in the Florida and USGA soils were very similar, with levels in 2012 being more pronounced than in 2011. In both of these soils, all fertilizer treatments leached statistically equal amounts of NH_4-N during 2011, ranging from 20.1 mg to 30.0 mg in the Florida sand soil and 20.5mg to 31.8mg in the USGA sand. During 2012, the greatest amount of NH_4-N was leached from the analog fertilizer treatment, followed by the E 15-0-0 fertilizer, and finally the UMAXX in both the Florida sand and USGA sand soils. In comparison, the Maryland sandy loam showed lower average amounts of NH_4-N leaching than observed in the other two soils. Differences in the magnitude of NH_4-N leaching in loamy sands and clay soils have been observed when compared to sandy soils (Guertal and Howe, 2012). The analog treatment showed the largest variability from 2011–12 in the Maryland sandy loam soil, and as a result, significant differences between fertilizer treatments were only observed during 2011, although the level and range of these differences was very small compared to the NH_4-N leaching seen during 2012 in the Florida sand and USGA sand soils. Because the analog treatment is a granular formula, there is a greater chance for unequal distribution of nitrogen in a small area. Another possibility is that analog applications made during 2011 may have contained less nitrogen by weight than during 2012 due to unforeseen sampling error when measuring out only a few grams of a granular fertilizer to be applied. Anecdotally, turf in 2012 was at a higher stress due to insect pressure. Non-stressed turf is essential to prevent the loss of nitrogen after a fertilizer application. Bowman et al. (1989) reported that after 48 hours, 75% of applied ammonium was absorbed by a turfgrass stand in good condition. Because fertilizer applications during a time of high stress could lead

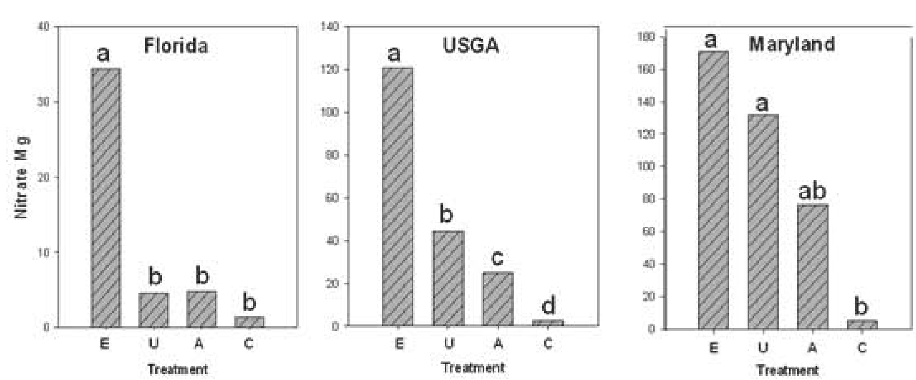

Fig. 1. Nitrate-Nitrogen (NO_3-N) leached from the soil over six weeks in studies conducted at the University of Georgia during 2011 and 2012. (E = E 15-0-0, U = UMAXX, A = analog, C = control) (Means within a soil graph shown with same letter are not significantly different at $P < 0.05$ according to Fisher's LSD).

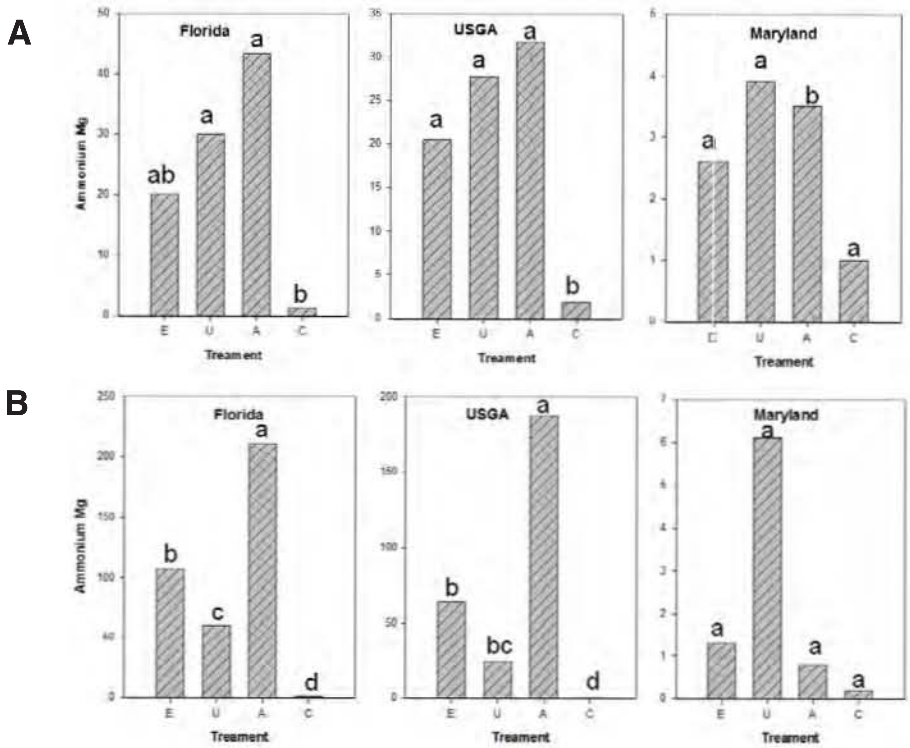

Fig. 2. (**A**) Ammonium-Nitrogen (NH4-N) leached from the soil over six weeks in studies conducted at the University of Georgia during 2011. (**B**) Ammonium-Nitrogen (NH4-N) leached from the soil over six weeks in studies conducted at the University of Georgia during 2012. (E = E 15-0-0, U = UMAXX, A = analog, C = control). Means within a soil graph shown with same letter are not significantly different at $P < 0.05$ according to Fisher's LSD.

to an inefficiency of the plant to utilize nitrogen, it would be beneficial to educate home owners and turfgrass managers about proper fertilization practices that could promote turf health with minimal environmental risks.

Conclusion

The E 15-0-0 fertilizer leached the largest amounts of NO_3-N on average from the two trials performed in 2011 and 2012. For NH_4-N, the analog fertilizer showed the highest amounts of leaching in the Florida sand and USGA sand soils, indicating an inefficiency for conversion to the more plant-available form of NO_3-N. Many environmental factors can affect the plant utilization, or possible leaching of a fertilizer. Input from turf managers would be important to determine the timing and environmental conditions which are commonly considered when applying fertilizer so that additional experiments can be designed to further study the impact of these fertilizers in conditions outside of the scope of this research.

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