Nitrogen leaching from contrasting liquid fertilizers applied to three soils

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Abstract
In recent years, new liquid fertilizers have been formulated to slowly release nitrogen. However, little information is known about their nitrogen release when applied to different soils. In two, 56 day greenhouse experiments, mineral nitrogen and total Kjeldahl nitrogen (TKN) leaching curves were determined by applying either no fertilizer, urea, or three controlled release liquid fertilizers to three soils: sand, a mix of 90% sand and 10% peat moss, and a sandy clay loam. All fertilizers leached quickly through the sand soil with no differences in N leached. The least leaching occurred from fertilizers applied to the sandy clay loam. In the second half of EXP2, urea released the greatest TKN when applied to the sandy clay loam, but not when applied to the other two soils. Controlled release liquid fertilizers influenced both mineral nitrogen and TKN leaching in different soils.

Key Words
Sandy clay loam, urea polymers, urea-ammonium nitrate, total Kjeldahl nitrogen

Introduction
Nitrogen (N) is the most essential turfgrass nutrient (Beard 1973). Turfgrass mangers have often applied urea because of its low cost and for the quick turfgrass green up that urea provides (McCarty *et al.* 2003). However because it is a soluble N source, what is not utilized by the turfgrass can potentially leach rapidly through the soil profile with subsequent irrigations and rainfall and can potentially contaminate receiving waters (Duncan *et al.* 2009). In addition, urea N can be lost by ammonia volatilization under optimal conditions (Carrow *et al.* 2001). Granular controlled release fertilizers have been documented to release N over a long period of time, allowing N to be continuously available to the plant, and resulting in uniform long term quality, and reducing fertilizer application frequency and the leaching potential to receiving waters (Carrow 1997; Cisar *et al.* 2005; Hummel 1989; Soldat *et al.* 2008).

Controlled release liquid fertilizers (CRLF) are relatively new compared to granular products. The main advantage of CRLF is that they can be tank mixed and applied with other chemicals or injected into the irrigation system. Eliminating the need to apply fertilizer separately may reduce time, financial, and labour resources. In addition, liquid fertilizers are not removed from close-cut turfgrass during mowing. These advantages have made CRLF appealing not only for high-end managed turfgrass, but also for sod production. Unlike their granular counterparts, relatively little information is known on the N release characteristics of CRLF, and even less on their N release from various soil types. The objective of this research was to determine N leaching from three CRLF and soluble urea from three contrasting soils.

Methods and Materials
Two greenhouse experiments (EXP1: April 09 – June 02, 2008, and EXP2: June 16-August 08^{h}, 2008) were conducted for 56 days each at the Clemson University Pee Dee Research and Education Center in Florence, South Carolina, USA, 29506. Leaching columns (10 cm in dia., 15 cm length) were constructed from PVC tubing with end caps. Plastic screening was glued to the bottom of the PVC. A 6.4 mm hole was drilled into the bottom of the end caps to allow for drainage and then glued to the screened end of the PVC tube. Wood racks supported the leaching columns and suspended them 15 cm off the bench. Plastic bowls were placed under each column to collect leachate. Each column was filled with one of the three soils to 2.5 cm from the top lip: size 45 sand (SAND), 90:10, size 45 sand:peat mix (MIX), and a sandy clay loam (SCL). The SCL was obtained from the Bt horizon of Lynchburg series soil (fine-loamy, siliceous, semiactive, thermic Aeric Paleaquult, Soil Survey Staff, NRCS 2009). Prior to experiment initiation, one litre of deionized water was applied to the soils and allowed to drain to achieve field capacity. The leachate was collected to determine baseline N. On the following day, one of five liquid fertilizers (FERT) was randomly applied on the surface of each column at a rate of 0.50 t N/ha (390 mg N per column): None (NONE), GP30 (22-0-0, 6% N from UAN, 94% N from urea polymers), GP44 (28.2-0-0, 71.8% N from UAN, 28.2% N from urea polymers),

GP83 (20-0-0, 81.2% N from urea, 18.8% N from urea polymers) and UREA (46.6-0-0, 100% urea). The UREA was included as a non-controlled release liquid standard. For EXP1, the columns were irrigated directly after fertilizer applications with 8.5 mm of water. The columns received 8.5 mm of water every M-W-F to simulate irrigation events. On Days 7, 21, 35, and 49, the lysimeters received 25 mm of water to simulate rain events. In EXP2, 12.7 mm of water was applied instead of 8.5 mm due to warmer temperatures resulting in drier soils and to ensure enough leachate could be collected for analysis. When leaching occurred, leachate was collected and the volume determined. Nitrogen release characteristics were determined by analysing the leachate for NH_4-N, NO_3-N, and total Kjeldahl nitrogen (TKN) using continuous flow injection colorimetry (QuikChem methods 10-107-04-1-O, 10-107-06-01-B and 10-107-06-2-I). Mineral nitrogen (MN) was determined by summing NO_3-N and NH_4-N. The experimental design was a randomized complete block design with three replications (n=45). Data were analysed by two-way ANOVA using SAS software (SAS Institute 2003). When differences in treatment means were determined to be significant, means were separated using the Waller-Duncan's K-ratio test.

Results

Leaching during EXP1 was observed from columns only at pre-treatment, the first-week irrigations and after the 25 mm rain events. In comparison, during EXP2, additional leaching was observed on some irrigation dates following a rain event. On these days, the leachate volume was not always sufficient for all N analyses, and thus NH_4-N and NO_3-N were analysed first. If TKN was not determined due to insufficient sample volume, the analytical results from the previous leaching date were used to represent a worst case scenario.

The SOIL x FERT effect was significant for all leaching dates after treatment application for MN in EXP1, and for the majority of leaching dates for MN and TKN in EXP2 (Table 1a and b). Specific interactions varied by date. However on many dates the interaction resulted from fewer differences among fertilizer treatments from the SAND compared to the MIX and SCL (Tables 2 and 3). Perhaps the lack of differences for the fertilizers in the SAND may be explained by greater porosity and lower volumetric water holding capacity common to soils without organic material and finer particles such as found in the MIX and SCL.

Table 1. Table of significance for mineral nitrogen (NO_3-N + NH_4-N) and TKN over the two experiments.

(a) MN	Day 0	Day 1	Day 3	Day 5	Day 7	Day 9	Day 11	Day 21	Day 23	Day 35	Day 49	Day 51	Total
EXP1													
SOIL	***†	***	***	---	**	---	---	***	---	***	***	---	**
FERT	ns	***	***	---	***	---	---	***	---	***	***	---	***
SOIL x FERT	ns	**	**	---	***	---	---	***	---	***	***	---	**
EXP2													
SOIL	***	**	**	***	***	ns	*	---	ns	***	***	***	***
FERT	ns	***	***	***	***	**	***	---	***	***	***	***	***
SOIL x FERT	ns	***	***	***	***	ns	***	---	ns	***	***	***	***
(b) TKN													
EXP1													
SOIL	***	ns	ns	---	ns	---	---	ns	---	***	***	---	ns
FERT	ns	ns	***	---	***	---	---	***	---	***	**	---	***
SOIL x FERT	ns	ns	ns	---	ns	---	---	ns	---	***	*	---	ns
EXP2													
SOIL	ns	***	***	***	***	ns	***	---	***	***	***	***	***
FERT	ns	**	*	***	***	ns	***	---	***	***	***	***	***
SOIL x FERT	ns	ns	**	**	ns	ns	**	---	ns	***	***	**	ns

†ns, *, ** and *** = P>0.10, P<0.10, P<0.05, and P<0.01 respectively. --- = no leaching occurred.

Mineral nitrogen

Before fertilizer was applied in EXP1, similar MN was leached from the SCL and MIX soils (0.26 and 0.24 mg respectively), which was greater than MN leached from the SAND (0.02 mg, Table 2). In EXP2, before fertilizer was applied, greater MN leached from the SCL soil (1.03 mg) compared to the SAND (0.74 mg), with both greater than from the MIX (0.52 mg, Table 1a). The greatest MN leached was after rain events (Tables 2 and 3). All fertilizers resulted in MN leaching on the first leaching date after fertilizer application (Tables 2 and 3). GP30 and GP83 resulted in more uniform MN release in the SCL and MIX soils (Tables 2 and 3). In both experiments and for all soils, applying GP44 resulted in the greatest MN leached on many days and in total (Tables 2 and 3). The high MN leaching of GP44 can be attributed to the high percent of

UAN within the fertilizer. From Day 35 onward in EXP2, MN leached from the UREA treatment was greater than all other fertilizer treatments (Table 3). The high MN recovery from applying no fertilizer (NONE) to the SCL in EXP1 may be from soil organic mater N mineralization (Table 2).

Table 2. Mineral nitrogen (NH_4-N and NO_3-N) leached (in mg) from fertilizer sources for each soil over EXP1.

(a) SAND	Day 0	Day 1†	Day 3	Day 7†	Day 21†	Day 35†	Day 49†	Total
GP44	0.00	0.34a	0.09	153a	0.12	0.04	0.04	154a
GP83	0.01	0.13b	0.01	4.69b	0.05	0.03	0.01	4.90b
GP30	0.02	0.20b	0.01	3.32b	0.09	0.01	0.01	0.19b
Urea	0.01	0.07b	0.01	0.61b	0.02	0.01	0.02	0.74b
None	0.00	0.01b	0.00	0.03b	0.01	0.00	0.02	0.07b
Significance	ns	**	ns	***	ns	ns	ns	***
(b) MIX								
GP44	0.23	1.31a	0.24a	88.3a	1.58a	2.64a	2.48a	96.6a
GP83	0.20	0.49bc	0.03b	0.85b	0.57c	0.74b	1.41b	4.09b
GP30	0.30	0.62b	0.04b	0.83b	1.11b	2.87a	2.47a	7.95b
Urea	0.22	0.35bc	0.03b	0.56b	0.55c	0.50b	0.66c	2.66b
None	0.25	0.09c	0.01b	0.28b	0.09d	0.04b	0.08c	0.60b
Significance	ns	***	***	***	***	**	***	**
(b) SCL								
GP44	0.14	1.86a	0.45a	42.4a	1.46a	0.81ab	1.17ab	48.6a
GP83	0.19	0.86b	0.10bc	0.85b	0.82b	0.41b	0.51bc	3.56b
GP30	0.28	1.86a	0.19b	0.95b	1.64a	1.63a	1.81a	3.50b
Urea	0.33	0.23c	0.04bc	0.60b	0.25c	0.13b	0.31c	1.55b
None	0.37	0.05c	0.01c	0.10b	0.11c	0.08b	0.18c	0.54b
Significance	ns	***	***	*	***	***	***	***

† represents rain event (25 mm of water applied). All other days are irrigation days (8.5 mm of water applied). ns, *, ** and *** = P>0.10, P<0.10, P<0.05, and P<0.01 respectively.

Table 3. Mineral nitrogen (NH_4-N and NO_3-N) leached (in mg) from fertilizer sources for each soil over EXP2.

(a) SAND	Day 0	Day 1†	Day 3	Day 5	Day 7†	Day 9	Day 11	Day 21†	Day 35†	Day 49†	Day 51	Total
GP44	0.77	0.26	18.4a	13.3a	50.9a	2.24	16.2b	1.68	2.92b	0.79	0.14	108a
GP83	0.67	0.15	0.54b	2.57b	11.9b	1.00	15.2b	2.28	1.74bc	0.87	0.07	37.0c
GP30	0.65	0.04	0.48b	2.67b	11.1b	0.52	18.4b	1.91	2.37b	0.65	0.08	38.9c
Urea	0.79	0.02	0.42b	2.18b	9.41b	0.00	30.3a	3.04	5.16a	0.63	0.02	52.0b
None	0.82	0.06	0.01b	0.01c	0.07b	0.01	0.21c	0.06	0.14c	0.11	0.07	1.52d
Significance	ns	ns	***	***	***	ns	***	ns	***	ns	ns	***
(b) MIX												
GP44	0.57	0.10	9.05a	8.83a	48.3a	2.95	33.4a	2.80	3.79ab	4.10a	2.26a	116a
GP83	0.51	0.23	0.18b	0.97b	4.77b	0.38	15.9b	2.52	5.67a	4.16a	1.29ab	36.2b
GP30	0.49	14.0	0.09b	0.94b	5.95b	0.34	11.5b	1.62	3.49b	2.95ab	0.74bc	28.3b
Urea	0.55	0.11	0.25b	0.63b	4.14b	0.43	8.09bc	2.59	4.54ab	4.35a	2.07a	27.7b
None	0.47	0.12	0.02b	0.03b	0.12b	0.59	0.23c	0.13	0.11c	0.07b	0.03c	1.91c
Significance	ns	ns	***	***	***	ns	***	ns	***	*	***	***
(b) SCL												
GP44	1.23	0.98a	1.45	2.86a	19.6a	1.40	28.5a	5.45a	9.77b	4.68c	1.50c	77.4a
GP83	1.06	0.13b	0.23	0.55b	4.42b	0.62	5.82b	1.90b	6.34c	10.3b	4.30b	35.7c
GP30	0.96	0.18b	0.26	0.66b	3.84b	0.41	6.48b	1.13b	3.52d	2.08cd	1.28c	20.8d
Urea	0.95	0.10b	1.55	0.55b	6.78b	0.20	7.60b	2.09b	12.6a	14.4a	5.53a	52.3b
None	0.95	0.06b	0.23	0.01b	0.08b	0.01	0.23b	0.09b	0.36e	0.39d	0.72c	3.13e
Significance	ns	***	ns	*	***	ns	***	***	***	***	***	***

† represents rain event (25 mm of water applied). All other days are irrigation days (12.7 mm of water applied). ns, *, ** and *** = P>0.10, P<0.10, P<0.05, and P<0.01 respectively.

Total Kjeldahl nitrogen

Before fertilizer was applied in EXP1, greater TKN leached from the SCL (0.76 mg) compared to the MIX (0.54 mg), with both greater than the SAND (0.23 mg, Table 1). Once fertilizer was applied, only FERT influenced TKN leaching until the last two leaching dates. As the experiment progressed, GP44 and GP30 resulted in the greatest TKN leaching, which were sometimes similar to other fertilizer treatments (Figure 1).

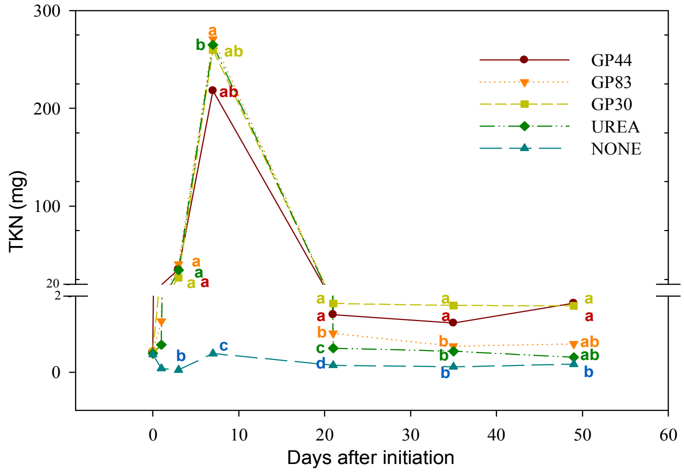

Figure 1. Total Kjeldahl nitrogen (TKN) leached from five fertilizer treatments over the EXP1. Means with the same letter within a column are not significantly different at the 0.10 significance level.

Pre-treatment TKN leachate from EXP2 was not influenced by any factor. Throughout EXP2 TKN leached was affected by SOIL and/or FERT but not their interaction (Table 1b): On Day7 and 23 of EXP2, TKN leached was greatest from SAND, the least from SCL, with the MIX always similar to the SAND (data not shown, Table 1b). Total TKN leached from SCL in EXP2 was approximately half of TKN leached from SAND and MIX (data not shown, Table 1b). On EXP2 days in which FERT influenced TKN leached (Table 1b), NONE resulted in the least amount of TKN losses. GP83, UREA, and GP30 had similar TKN leaching, which was less than GP44 (data not shown, Table 1b). The recovery differences between the soils in EXP2 may be explained by there being sufficient soil water for microbially mediated mineralization and immobilization.

In summary, the two CRLFs with high % urea polymers (GP30 and GP83) resulted in less than or similar MN and TKN leaching than the UREA. The CRLF with minimal % urea polymers (GP44) resulted in the most leaching.

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