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SYMPOSIUM ON PESTICIDE AND NUTRIENT FATE UNDER TURFGRASS GOLF COURSE CONDITIONS

Leaching and Mass Balance of ^{15}N-Labeled Urea Applied to a Kentucky Bluegrass Turf

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ABSTRACT

The fate of urea applied to Kentucky bluegrass (*Poa pratensis* L.) turf was studied over a 2-yr period using a combination of intact monolith lysimeters and small plots. Soil type was a Marlette fine sandy loam (fine-loamy, mixed mesic Glossoboric Hapludalfs). Urea was applied at a rate of 196 kg N ha^{-1} yr^{-1} in five equal applications of 39.2 kg N ha^{-1}, using two application schedules. Treatments were fertilized at approximately 38-d intervals with the "Spring" treatment fertilized from late April through late September and the "Fall" treatment from early June through early November. In 1991 only, the April and November applications used ^{15}N-labeled urea (LFN). For the Spring treatment, 31% of LFN was recovered from thatch at 18 DAT. This value remained constant for the next year, then gradually declined to 20% after 2 yr. Only 8% of the LFN was recovered from soil at 18 DAT and increased to only 20% 2 yr after application. Approximately 35% of the LFN was harvested in clippings over 2 yr. Through May 1993 (748 DAT), LFN in leachate totaled 0.18% of the amount applied. For the Fall treatment, 62% of the LFN was recovered from thatch at 18 DAT. This value declined to 35% by the following June. LFN in soil increased from 12% to 25% over 2 yr. Approximately 38% of the LFN was harvested in clippings over 2 yr. Total leachate LFN recovery was 0.23% over the 2-yr period. Total recovery of LFN was 64 and 81% for the Spring and Fall treatments, respectively, suggesting volatile losses of N. Whether the N was applied in the spring or late fall, rapid uptake and immobilization of the LFN resulted. A maximum of 25% of applied LFN was recovered in the soil from either application timing at any time over the 2 yr of the experiment. A well-maintained turf intercepts and immobilizes LFN quickly making leaching an unlikely avenue of N loss from a turf system.

LATE FALL (early to mid-November) N fertilization of cool season turf has been recommended for many years. Wilkinson and Duff (1972) found that N fertilization of Kentucky bluegrass on 15 November did not induce a growth or color response through the winter, but plants had higher chlorophyll contents and enhanced growth and color in mid-April compared with plants fertilized earlier in the Fall. These characteristics are desirable in turfgrass culture. However, leaching of fertilizer nitrogen (FN) applied to turf has received much attention in recent years, and the fate of late fall N applications may be of special concern due to slow growth rates and potential lack of plant uptake.

Studies of N fate under turf management conditions are limited; however, investigations into certain aspects of N fate such as leaching or plant uptake are more plentiful and have recently been reviewed by Petrovic (1990). Starr and DeRoo (1981), using a Kentucky bluegrass-red fescue (*Festuca rubra* L.) turf, observed that where clippings were not returned, total N removed during mowing averaged 95 kg ha^{-1} yr^{-1} over three years, equivalent to 50% of the FN applied. Where clippings were returned, harvested N averaged 137 kg ha^{-1} yr^{-1} (73% of applied FN). By using ^{15}N-labeled ammonium sulfate, LFN uptake of approximately 30 kg ha^{-1} (35% of the total applied) was measured during a 120-d period following a May application and 20 kg ha^{-1} (20% of the total applied) following a September application, regardless of clipping management. Total N uptake, LFN uptake, and dry matter accumulation were rapid for a period of approximately three weeks following application. Bowman et al. (1989) applied 50 kg N ha^{-1} as ^{15}N-labeled ammonium sulfate to Kentucky bluegrass, followed by 0.3-cm irrigation, and recovered 75% of the LFN in plant shoots at 5 DAT. Bristow et al. (1987) applied ^{15}N-ammonium nitrate at a rate of 60 kg N ha^{-1} to perennial ryegrass (*Lolium perenne* L.) under pasture conditions. They observed recoveries in herbage of 33, 49, and 55% for the periods 28, 111, and 370 DAT, respectively. Inclusion of stubble raised these recoveries to 53, 54, and 56%.

Thatch can be a significant source and sink for FN.

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Abbreviations: LFN, labeled fertilizer nitrogen; FN, fertilizer nitrogen; DAT, days after treatment.

Starr and DeRoo (1981) found that a bluegrass-fescue thatch had a total N content equivalent to 280 or 510 kg N ha^{-1} where clippings were removed or returned, respectively. Immobilization in the thatch of approximately 40 kg LFN ha^{-1} (180 kg LFN ha^{-1} applied) was measured during one growing season. In extracted Kentucky bluegrass cores in the laboratory, under suction to simulate leaching, 46% of N applied as urea and 67% of N applied as IBDU remained in the thatch after 15 d (Nelson et al., 1980). Thirty minutes after application of either calcium nitrate or ammonium sulfate to Kentucky bluegrass, Bowman et al. (1989) recovered approximately 29% of the NO_3-N and 46% of the NH_4-N in the thatch. At 4 DAT, almost no NO_3-N or NH_4-N was recoverable by KCl extraction. They attributed this low recovery to biological immobilization.

Rieke and Ellis (1974) observed that high application rates of NH_4NO_3 (290 and 390 kg N ha^{-1} on fine sandy loam and sandy soils, respectively) resulted in downward movement of NO_3-N during the early summer. Brown et al. (1977; 1982) observed nitrate leaching from sand-based putting greens, with greater leaching occurring from soil mixtures with higher sand contents. Mitchell et al. (1978) attributed higher leaching rates in certain putting green soil mixtures to higher total N content, as opposed to soil texture. Morton et al. (1988) observed mean annual concentrations ≤ 4 mg NO_3-N L^{-1} in percolate from a sandy loam soil in Connecticut supporting a bluegrass-fescue lawn under a variety of fertilization rates and irrigation schedules. Over a 2-yr period, Starr and DeRoo (1981) found no increase in groundwater NO_3-N concentrations (2.0 mg NO_3-N L^{-1}) beneath fertilized sandy loam plots as compared to samples collected upstream (1.8 mg NO_3-N L^{-1}). After fertilizing the Kentucky bluegrass lawn with ^{15}N-labeled $(NH_4)_2SO_4$, ^{15}N was detected in percolate only one time, and the concentration was near background levels. Morton et al. (1988) and Starr and DeRoo (1981) concluded that under management practices common to home lawns, the risk of groundwater contamination from FN is extremely low.

Although much work has been done investigating various aspects of N fate in turfgrass environments, only one published work has attempted to construct a mass balance for fertilizer N (Starr and DeRoo, 1981). Following application of 180 kg N ha^{-1} as $(NH_4)_2SO_4$, recovery in clippings, thatch, and soil were approximately 30, 19, and 24% where clippings were removed and 30, 27, and 21% where clippings were returned. The authors concluded that leaching losses were negligible (although not quantitatively measured), microbial activity was extremely important in immobilizing the FN (not measured), and unrecovered amounts were attributed to gaseous loss

The purpose of the present study was to construct a mass balance for FN applied to turf in the early spring or late fall, paying special attention to quantitative leachate collection, soil transformations, plant uptake, and soil microbial activity.

MATERIALS AND METHODS

Four intact monolith drainage lysimeters were constructed at the Hancock Turfgrass Research Center at Michigan State University between the fall of 1989 and the summer of 1991. The site had been in turfgrass for 6 yr prior to construction of the lysimeters. Soil type was a Marlette fine sandy loam (62:22:16/% sand:silt:clay) with a pH of 7.3. Total N in the soil, determined by combustion, was 783 kg ha^{-1}. The cylindrical lysimeters were constructed of grade 304 stainless steel 0.5 cm thick, 1.14 m in diameter (1-m^2 surface area), and 1.2 m deep. The bottoms of the lysimeters have a 3% slope so that leachate drains to a tube on one side. To construct each lysimeter, a soil monolith was exposed by excavation in increments of approximately 20 cm, and the open-ended container was placed over the monolith and downward pressure applied to slide the container over the monolith. When the containers were installed completely over the cores, they were removed from the hole, inverted, and a 3-cm layer of soil was removed from the bottom of the core and replaced with 1- to 2-cm-diam pea gravel. A stainless steel bottom and drain tube were then welded into place. The core was then reinverted and placed back in the ground atop a manhole structure that provided access to the lysimeter bottom for percolate sampling. Excavation holes were then backfilled, matching soil types for each distinct layer of the profile.

In September 1990, the area was sodded with a blend of 'Adelphi', 'Nassau', and 'Nugget' Kentucky bluegrasses (equal proportions by weight at seeding). In March 1991, microplots for soil sampling were installed adjacent to the lysimeters to be used for destructive soil sampling. The microplots were constructed of 20-cm-diam polyvinylchloride piping, 60 cm in length and were installed in undisturbed soil. The microplots were pushed directly into the soil with a hydraulic cylinder. This method preserved the native soil structure within the microplots and the surrounding area. A total of 64 microplots were installed in a randomized complete block layout with four replications (2 fertilizer treatments $\times$ 8 sampling dates $\times$ 4 replications).

The two fertilizer treatments in the study were defined by application timing. Both treatments received a total of 196 kg N ha^{-1} yr^{-1} as urea, applied in five equal applications of 39.2 kg N ha^{-1}. The 'Spring' treatment received its first application on 26 April 1991, and succeeding applications at approximately 38-d intervals, with the final application on 27 September. The schedule for the Fall treatment began with a 4 June 1991 application and ended with an 8 Nov. 1991 fertilization. Both treatments received four fertilizations at the same timing with the fifth application in late April for the Spring treatment and in early November for the Fall treatment. The April and November applications in 1991 only were made with ^{15}N-labeled urea (24.9613 atom % excess in April, 25.2283 atom % excess in November). The 1992 and 1993 fertilizer application dates were similar to those in 1991.

The ^{15}N-labeled fertilizer was poured on to each lysimeter and microplot as a dilute solution in 0.5 mm water. Immediately following fertilization, an additional 4.5 mm water was applied using the same container to ensure that all of the labeled fertilizer was applied. Based upon soil tests, no additional P fertilizer was required. However, K levels were medium to low and so K_2O was applied at 50 kg ha^{-1} on 9 Sept. and 12 Oct. 1990, 6 June 1991, 17 June and 2 Sept. 1992, and 24 July and 24 Sept. 1993.

Leachate was collected from the lysimeters in 19-L glass jars. Jars were emptied when approximately 1/2 full, usually every 7 to 10 d, but sometimes more or less frequently depending on precipitation patterns. Leachate volume was re-

Table 1. Analysis of variance for spring or fall applied labeled fertilizer nitrogen. Sampling depths were clippings, verdure, thatch, and soil.

Source	df	Spring	Fall
		mean square	
Sampling dates	6	13.35	32.36**
Rep	3	2.56	3.34
Error a	18	6.25	7.27
Depth	3	259.69**	415.66**
Sampling Date & Depth	18	74.24**	128.67**
Error b	63	4.35	6.89
CV		26.9	30.0

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

corded and approximately 100 mL was saved in a 125-mL polypropylene bottle and frozen until analysis.

Clippings were collected approximately weekly throughout the growing season. Hand clippers were used to cut the grass while holding a hand-held vacuum against the clippers to quantitatively collect clippings. Clippings were dried at 65°C for 72 h then ground to pass an 80-mesh screen prior to analysis.

Four microplots were excavated for soil N analysis according to the schedules indicated in Tables 1 and 2. Four untreated microplots were excavated on 14 May 1991 to serve as background levels for N and ^{15}N analysis. There were four sampling dates in the first year following ^{15}N application and two sampling dates in the second year. For both treatments, the first sample was taken 18 d after application and the final sample was removed approximately 750 d after application.

Microplots were removed intact and split open longitudinally to expose the soil core within. Microplot cores were sectioned into verdure, thatch, and 0- to 5-, 5- to 10-, 10- to 20-, 20- to 40-, and 40- to 60-cm soil depths. Verdure and thatch samples were dried at 65°C for 72 h. Thatch samples were separated into organic and soil fractions by hand massaging because different grinding methods were used for soil or organic fractions. Verdure and thatch organic matter were ground to pass an 80-mesh screen with a Wiley mill. Thatch soil was prepared for total N and ^{15}N analysis by pulverizing into a fine powder.

Three subsamples were removed from each soil depth increment. One was dried at 65°C for 72 h, then pulverized for N and ^{15}N analysis. Another subsample was stored at 5°C for 2 to 5 d for microbial biomass determination (data not presented). The third subsample was frozen at −25°C.

Concentrations of NO_3 and NH_4 in leachate were determined colorimetrically using a Lachat QuikChem autoanalyzer (Lachat Instruments, Milwaukee, WI). Samples were prepared for ^{15}N determination by the diffusion method of Brooks et al. (1989). Because of very low NO_3 and NH_4 concentrations, a single diffusion for both species was performed and ^{15}N analysis of leachate was for (NO_3 + NH_4).

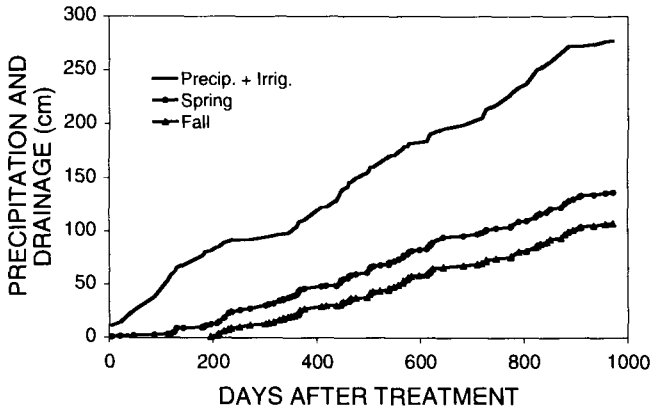

Fig. 1. Total precipitation plus irrigation received on the lysimeter site and cumulative drainage from lysimeters treated with spring applied N schedule, 'spring', or with late fall applied N schedule, 'fall'.

Total N content of clippings, verdure, thatch, and soil; ^{15}N enrichment of these samples; and all diffusion samples were determined using a Europa Scientific Roboprep C-N Biological Sample Converter and Tracermass mass spectrometer (Europa Scientific USA, Cincinnati, OH). Duplicate analyses were conducted for each sample.

The microplot data were analyzed statistically as a split-plot in time design (Steel and Torrie, 1980) with time serving as main plots and depth as subplots. "Depths" included clippings, verdure, thatch, and soil (total of all soil depths). Clipping data were totaled to include all clipping collection dates up to the respective soil sampling date. Timing of ^{15}N applications and soil sampling dates resulted in unequal time intervals between treatment application and soil sampling for the two fertilization schedules. For this reason, fertilizer application timing was not included as a variable in the analysis. In this sense, the two treatments were analyzed as separate experiments. However, the first and last samples, that were collected at 18 and approximately 750 d following application, permitted direct comparisons for both treatments at these two dates. Statistical analyses were conducted using SAS (SAS Institute, 1989).

RESULTS AND DISCUSSION

Between 26 April 1991 and 16 Nov. 1993, 218 cm of precipitation and 56 cm of irrigation fell on the lysimeters, for a total input of 274 cm of water (Fig. 1). Total drainage was 134 cm for the Spring treatment (4/26/91–11/16/93) and 108 cm for the Fall treatment (11/8/91–11/16/93). Drainage for the Spring treatment during the same time period as collected for the Fall treatment was

Table 2. Recovery of labeled fertilizer nitrogen (LFN) from each canopy increment and total percent recovery at each sampling date from a single application of 39.2 kg labeled N ha^{-1} on 26 Apr. 1991.

Date	DAT	Clippings	Verdure	Thatch	Soil	Leachate	Total	% Recovery
		kg LFN ha^{-1}						
14 May 1991	18	0.94	14.25	12.15	3.16	0.000	30.50	78
21 June 1991	56	7.83	8.02	12.24	4.31	0.000	32.40	83
14 Oct. 1991	141	11.89	3.36	7.43	6.16	0.000	28.84	74
26 Nov. 1991	214	12.09	3.03	12.54	6.74	0.000	34.39	88
26 May 1992	395	12.86	1.53	13.72	7.95	0.004	36.06	92
30 Nov. 1992	578	13.72	0.97	8.38	6.56	0.004	29.63	76
14 May 1993	748	13.89	0.68	5.23	5.34	0.005	25.14	64
FPLSD*		0.44	4.27	3.97	2.81	NS	NS	

* Fisher's Protected LSD at P = 0.05.

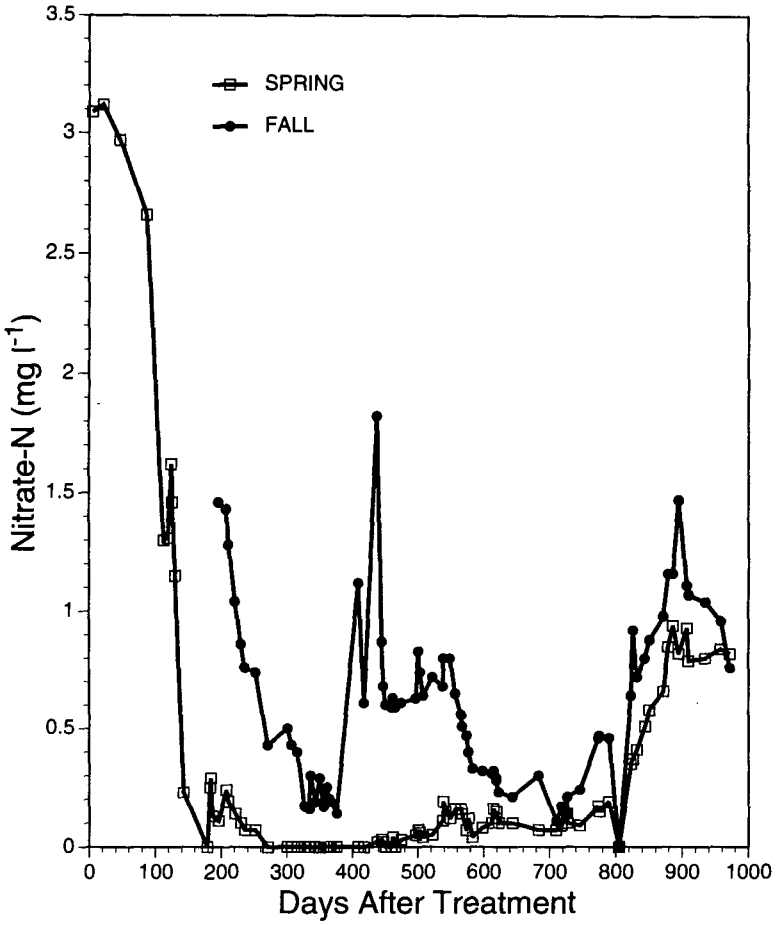

Fig. 2. Concentrations of NO_3-N in the lysimeter percolate from the spring applied N schedule and the late fall applied N schedule.

122 cm. Total drainage was not significantly different between treatments.

Leachate

Nitrate concentrations in leachate were generally below 1 mg NO_3-N L^{-1} for both treatments throughout most of the experiment (Fig. 2). Exceptions to this occurred early in the experiment, and were probably due to enhanced mineralization caused by soil disturbance around the edges of the lysimeter cores during construction. Concentrations were again elevated near the end of data collection, but these levels were well below the EPA threshold level of 10 mg NO_3-N L^{-1}. Mean inorganic N concentrations in leachate for the entire term of the experiment were 0.31 mg NO_3-N L^{-1} and 0.12 mg NH_4-N L^{-1} for the Spring treatment, and 0.63 mg NO_3-N L^{-1} and 0.14 mg NH_4-N L^{-1} for the Fall treatment. Brown et al. (1982) reported NH_4 present in leachate from golf greens at low concentrations that were typically ≤ 1 mg NH_4-N L^{-1}.

Between 4/26/91 and 5/11/93 (745 DAT) a total of 3.3 kg N ha^{-1} and 0.005 kg LFN ha^{-1} was collected in leachate from lysimeters receiving the Spring treatment (Fig. 3A). By 16 Nov. 1993 (934 DAT), these values had increased to 5.6 kg N ha^{-1} and 0.09 kg LFN ha^{-1}. For the Fall treatment a total of 8.1 kg N ha^{-1} and 0.07 kg LFN ha^{-1} was recovered in leachate through 16 Nov. 1993 (738 DAT) (Fig. 3B). These values represent 0.23 and 0.18% of the LFN applied for the Spring and Fall treatments, respectively. Most of the LFN detected was found in a few isolated events during the Fall of 1993 when sample ^{15}N enrichment was high (Fig. 3). These isolated events were unusual because they appeared as discrete bands of ^{15}N with little additional ^{15}N found in samples taken immediately before or after the enriched samples. Apparently, diffusion during downward movement was minimal. These data indicate that N fertilization of turf, even in the late fall, does not pose a great risk to groundwater supplies.

Turf-Thatch-Soil

The overall analyses of variance for LFN recovery showed a significant sampling time × depth interaction (Table 1). Leachate N was not included in the analysis because that data came from different experimental units (lysimeters) than clipping, verdure, thatch, and soil data (microplots).

Cumulative recovery of LFN in clippings from the Spring treatment increased continuously throughout the experiment (Table 2). This was coincident with decreasing LFN content of verdure, indicating upward transport of LFN in shoot tissue throughout the experiment. Total LFN recovery in clippings over a period of 2 yr was 35% of that applied, similar to the 30% reported by

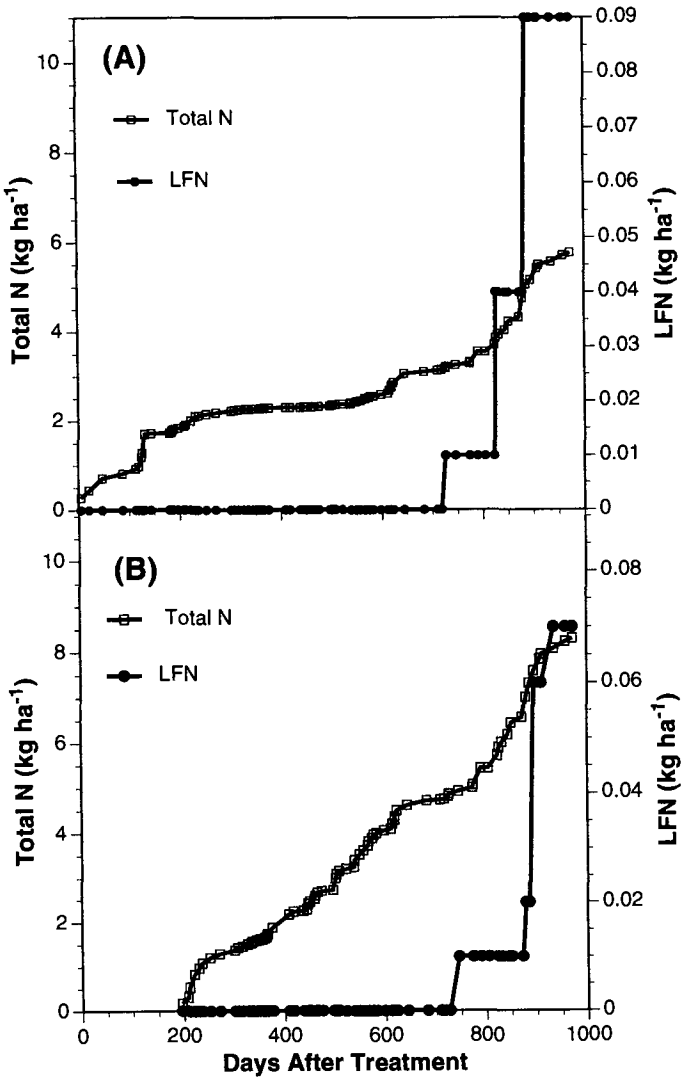

Fig. 3. Total N and labeled fertilizer nitrogen, LFN, for the spring applied N schedule, A, and for the late fall applied N schedule, B.

Starr and DeRoo (1981). Summing LFN in clippings and verdure at each date (data not shown) indicates that LFN in above ground plant tissue did not change significantly over time. All LFN recovered from shoot tissue was transported there within 18 DAT. This is consistent with data reported by Bristow et al. (1987) who found that LFN recovery in herbage plus stubble in a perennial ryegrass pasture ranged from 49.9 to 55.8% between 16 and 310 DAT.

Thatch was a significant sink for LFN. Thirty-one percent of spring applied LFN was recovered in thatch at 18 DAT (Table 2). This level remained consistent through May 1992 (395 DAT), with the exception of the October 1991 sample. The reduced recovery at this time was probably due to a sampling error (smaller thatch sample weight). Thatch LFN decreased significantly after May 1992, presumably because of mineralization or possibly gaseous losses. Soil LFN increased significantly between 18 and 171 DAT (14 Oct. 1992), and continued to increase through 395 DAT (26 May 1992). Mineralization of LFN from thatch and downward transport into the soil was the likely source of this increase, but because thatch LFN did not significantly change from May 1991 to May 1992, it is difficult to conclude this absolutely. Note that total recovery also increased during this period, although not significantly. These fluctuations were probably due, at least in part, to sample variability and mixing. Recovery of LFN from soil was never greater than 20% of the amount applied.

Amounts of LFN recovered in leachate were negligible, and in fact were not significantly different from zero (Table 2). These values made no real impact on the overall mass balance for LFN over the 2-yr period. Total LFN recovery ranged from 25.1 kg ha^{-1} (64%) to 36.1 kg ha^{-1} (92%), but the differences were non-significant.

Recovery of LFN in clippings and verdure for the Fall treatment followed similar patterns as observed with the Spring treatment (Table 3). Although fluctuations in total shoot LFN (clippings plus verdure) were greater for the fall treatment, it is still evident that most of the LFN recovered in shoot tissue was transported there within 18 DAT, even following a November application. Increased shoot growth was not observed during this time. Transport of LFN upward through the shoot commenced the following spring. Total recovery of LFN in clippings over 2 yr was 38% of the amount applied.

Thatch LFN accounted for 62% of applied N at 18 DAT, and thatch LFN did not change significantly by the following May (Table 3). This N was immobilized in the thatch layer since if it had remained present as urea or some other free inorganic species, it would have been leached from the thatch layer during mid-winter and spring snow melts. Between 199 DAT (26 May 1992) and 233 DAT (29 June 1992) there was significant loss of LFN from thatch, which coincided with a significant decrease in total LFN recovery. A trend of decreasing thatch LFN for the Fall treatment continued through the end of the study, but differences were not significant. The large thatch LFN decreases occurred in the same calendar year for both treatments, which represented the first season after application for the Fall treatment and the second season for the Spring treatment. This indicates a probable environmental effect, which would further implicate volatile loss mechanisms, most probably denitrification.

Soil LFN increased significantly between September 1992 and November 1993 for the Fall treatment. These increases followed the decreasing thatch LFN, indicating possible downward movement of mineralized LFN from the thatch. A maximum of 25% of the applied LFN was recovered in soil 2 yr after application. Although there was a trend toward increasing leachate LFN for the Fall treatment, the total amount was negligible.

Total LFN recovery for the Fall treatment ranged from 30 kg ha^{-1} (77%) to 43.1 kg ha^{-1} (109%) (Table 3). As noted previously, a significant decrease in total recovery occurred between May and June of 1992, but total recovery did not change significantly thereafter. Recovery of 78% of LFN at 18 DAT for the Spring treatment and continued recoveries of approximately 80% throughout the first summer suggested possible volatile losses shortly after application. Gaseous losses were not measured directly in this experiment, and so can only be inferred. One possible source for the variation

Table 3. Recovery of labeled fertilizer nitrogen (LFN) from each canopy increment and total percent recovery at each sampling date from a single application of 39.2 kg labeled N ha^{-1} on 8 Nov. 1991.

Date	DAT	Clippings	Verdure	Thatch	Soil	Leachate	Total	% Recovery
		kg LFN ha^{-1}						
26 Nov. 1991	18	0	14.01	24.28	4.77	0.000	43.1	109
26 May 1992	199	8.49	8.9	21.93	3.76	0.000	43.1	109
29 June 1992	233	10.5	7.59	13.88	2.76	0.001	34.7	89
17 Sept. 1992	282	12.09	2.55	9.57	6.31	0.001	30	77
30 Nov. 1992	387	12.38	1.74	9.93	6.1	0.002	30.1	77
14 May 1993	552	12.73	1.15	8.58	8.79	0.008	31.2	80
30 Nov. 1993	752	15.02	0.27	6.69	9.96	0.067	31.9	81
FPLSD*		0.58	2.29	7.07	2.93	NS	8.28	

* Fisher's Protected LSD at $P = 0.05$.

in recoveries was that at each sampling date, different experimental units (microplots) were sampled. Examination of the data reveals that total recovery is closely associated with soil LFN through May 1992 (with the exception of the October 1991 sample, where the decrease in total recovery can be related to thatch LFN). Total weight of the excavated soil samples was several kg, while LFN analyses for these samples were conducted on subsamples weighing 30 to 50 mg. Sampling and mixing could account for much of the variation seen; however, pairs of subsamples analyzed for each sample tended to be in close agreement (data not shown). Decreases in total recovery between May 1992 and May 1993 appear to be most closely related to decreases in thatch LFN, with soil LFN following a similar trend. Although the same type of sampling variation could be involved with thatch analyses as that which played a role in the soil analyses, the consistency of recovery in thatch through the first year implies that the thatch effect is real. Losses of LFN from thatch through mineralization and subsequent volatilization between May 1992 and May 1993 are probable. It has been demonstrated that thatch provides a conducive environment for NH_3 volatilization (Bowman et al., 1987; Torello and Wehner, 1983). However, the magnitude and timing of the loss in LFN recovery, between 26 May 1992 and 29 June 1992 for the Fall treatment and between 26 May 1992 and 30 Nov. 1992 for the Spring treatment, would imply that denitrification is the most likely loss mechanism. The loss in LFN recovery occurred at least 199 or 395 d after urea application for the Fall and Spring treatments, respectively, when $^{15}NH_4$ concentrations should be near zero.

Table 4. LFN recovery in each canopy increment at 18 and 750 d after treatment.

Days after treatment	Canopy location	Treatment	
		Spring	Fall
		kg LFN ha^{-1}	
18	Clippings	0.94	0**
	Verdure	14.25	14.01
	Thatch	12.15	24.28*
	Soil	3.16	4.77
	Leachate	0.00	0.00
	Total	30.50	43.06**
750	Clippings	13.89	15.02*
	Verdure	0.68	0.27
	Thatch	5.23	6.69
	Soil	5.34	9.96*
	Leachate	0.01	0.07**
	Total	25.15	32.01**

*,** Means within a row are significantly different by Fisher's Protected LSD at $P = 0.05$ and 0.01, respectively.

Application Times

The first microplot sample was collected 18 DAT for each treatment, and the last sample was collected 750 DAT, and so direct comparisons between treatments were made for these two sampling times (Table 4). The significant difference in clipping LFN recovery at 18 DAT occurred because no clippings were harvested up to this time for the Fall treatment. The Fall treatment had significantly higher thatch LFN, and significantly higher total recovery. The greater total recovery was primarily due to greater recovery of thatch LFN. This further implicates volatile losses from Spring applied LFN, because of the occurrence of environmental conditions in April more conducive to volatility than those that occur in November. After 2 yr, significantly more LFN was recovered in clippings for the Fall treatment than the Spring treatment. Late Fall N application also resulted in significantly greater LFN in leachate, although the total amount was negligible. Two years after application, there was greater recovery of LFN in soil for the Fall treatment than the Spring treatment, and greater total recovery. Greater soil LFN for the Fall treatment was due, at least in part, to immobilization of N in the thatch layer immediately following application. Although this higher soil LFN could indicate greater leaching potential, plant utilization of this N would lead to greater fertilizer use efficiency.

Data from this experiment indicates that N fertilization of Kentucky bluegrass, even in the late Fall, poses very little potential for significant groundwater contamination where turf density and organic matter content (thatch) is high. Thatch serves as an important environmental buffer, intercepting and cycling fertilizer N and preventing a large portion of the N from reaching the soil. Further investigation into the role of turfgrass thatch in N cycling and losses is needed.

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