PAPER IV

The fate of ^{15}N ammonium sulfate applied to Kentucky bluegrass and perennial ryegrass turfs

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Additional Index Words: ammonium sulfate, ^{15}N, labeled-N, Kentucky bluegrass, mass balance, perennial ryegrass

Abstract

Turfgrasses commonly used for athletic fields and home lawns in colder regions possess different growth patterns, causing differences in both total nitrogen efficiency and mobility of fertilizer nitrogen. This study was conducted to compare the fate of nitrogen in a thatchy Kentucky bluegrass (*Poa pratensis* L.) and a non-thatch producing perennial ryegrass (*Lolium perenne* L.) turf. The effects of sampling time and sampling depths on the distribution and cycling of labeled fertilizer nitrogen (LFN) were investigated using thirty-six microplots installed on a Marlette sandy loam soil (fine-loamy, mixed, mesic Glossoboric Hapluadalfs). Ammonium sulfate was applied at a rate of 293 kg ha^{-1} yr^{-1} in six equal applications of 48.8 kg N ha^{-1}, with the first application using ^{15}N-labeled $(NH_4)_2SO_4$. Four microplots from each turf type were excavated on 17 June, 6 July, and 10 August of 1994 and on 15 June of 1995 for nitrogen analysis. Total recoveries of LFN at 365 days after treatment (DAT) were 67% and 77% for perennial ryegrass and Kentucky bluegrass, respectively. Two days after treatment, however, the Kentucky bluegrass LFN recoveries in shoot tissue, thatch, and soil were 34%, 38%, and 20% of the total LFN applied. These values changed to 47%, 20%, and 9% at 365 DAT. For perennial ryegrass, the corresponding values were 25%, 28%, and 27% at 2 DAT and 43%, 10%, and 14% at 365 DAT. Thatch was a better N sink than mat, but the latter also demonstrated high immobilizing ability. Some downward movement of LFN was found, particularly in the perennial ryegrass microplots. However, the very small LFN concentrations found in the 20-40 cm soil layer, does not implicate downward leaching as a major pathway for N loss. Soil LFN was primarily found in the upper 0-5 cm, as organic nitrogen.

Introduction

Maintaining a healthy, suitable playing surface with high levels of wear tolerance, aesthetic quality, and an acceptable rate of turf growth, requires efficient use of fertilizers. However, environmental concerns exist regarding the application of fertilizer to golf greens and soccer fields, especially those constructed with sandy rootzone mixtures. Leaching of nitrates and contamination of groundwater have been studied carefully, and are discussed in reviews by Petrovic (1990) and Walker & Branham (1992). The loss of fertilizer nutrients, especially nitrogen, is not only attributed to downward leaching, but also to plant uptake, soil storage and gaseous losses. A number of studies have examined each of these N pools (Petrovic, 1990). Only a few published works, however, have attempted to construct a mass balance of fertilizer N in the entire turfgrass system using labeled carriers (Starr and DeRoo, 1981; Miltner et al., 1996). Both studies reported a total recovery of labeled fertilizer nitrogen (LFN) between 60% and 80%, and unrecovered amounts were attributed to gaseous loss. Both studies also indicated that the thatch layer was a significant sink for fertilizer N. Thatch, defined as a tightly intermingled layer of dead and living stems and roots that develops between the zone of green vegetation and the soil surface (Beard, 1973), contained between 20% and 35% of LFN at the end of these two studies. Miltner et al. (1996) found 31% recovery of LFN in thatch 18 days after spring application to a Kentucky bluegrass turf, and nearly 20% two years later. Bowman et al. (1989) determined that N uptake in the thatch was very rapid and that applied N is quickly immobilized. Mineralization of N in thatch organic matter to plant available N forms will depend upon complex microbial transformation and, thereby, have a time varying effect for different turfgrass systems.

Thatch should play a significant role in the fate and cycling of applied fertilizer nitrogen in turfs that develop a thatch layer. However, not all turfgrass species develop a thatch layer. Bunch type grasses such as perennial ryegrass more often have a mat layer, which is partially decayed organic matter from leaves, stems, etc. that has become part of the soil profile (Beard, 1973). The difference in the extent and development of thatch or mat layers suggests that the distribution and cycling of fertilizers in a perennial ryegrass turf may be significantly different from a Kentucky bluegrass turf, yielding differences in both total N efficiency and in the downward mobility of fertilizer N.

The objectives of this study were to compare the fate of N in two different turfgrass species, Kentucky bluegrass and perennial ryegrass, that possess different growth habits yielding differences in thatch or mat development. The use of ^{15}N-labeled fertilizer permitted the measurement of the distribution, uptake and cycling of N applied in these two species.

Materials and Methods

This study was initiated in June 1994, when a total of thirty-six microplots were installed at the Hancock Turfgrass Research Center on the campus of Michigan State University. Microplot construction, sample collection and methods of analysis have been described in detail by Miltner et al. (1996), but some modifications to the procedures were done in the present study. The microplots were constructed from 20 cm diameter PVC pipes with a total length of 40 cm. To limit soil resistance during installation, each microplot was bevelled to 45° at the leading edge. A tractor mounted hydraulic ram was used to push the microplots directly and smoothly into the soil, keeping an undisturbed soil structure in both microplots and surrounding areas. Two different turfgrass systems were compared, a thatchy 'Kenblue' Kentucky bluegrass turf and a 'Palmer' perennial ryegrass turf with a mat layer. The thatch layer was approximately 2.5 cm thick, containing a heterogenous mix of dead and living plant tissue and some soil particles. The mat layer was partly decayed organic matter mixed with soil material. Both turfgrasses were grown on a Marlette sandy loam soil (fine-loamy, mixed, mesic Glossoboric Hapluadalfs). The particle size distributions were 59% sand, 27% silt and 14% clay for the Kentucky bluegrass site, and 53% sand, 27% silt and 20% clay for the perennial ryegrass site.

All treatments received a total of 293 kg N ha^{-1} as $(NH_4)_2SO_4$ over the course of the study, applied in six applications of 48.8 kg N ha^{-1} on 15 June, 20 July, 19 August, 24 September, and 22 November of 1994, and on 1 June of 1995. The first application was made with ^{15}N-labeled ammonium sulfate (24.7498 atom-% excess). The ^{15}N-labeled fertilizer was applied as a solution in 50 ml of water to thirty-two of the microplots. The remaining four plots, two on each turfgrass stand, were used as non-fertilized control treatments. To ensure that all of the fertilizer solution was applied to the microplot, an additional 100 ml of water was applied from the same container immediately after fertilization. After all microplots were fertilized and irrigated, each plot was covered with a bucket and the surrounding area was fertilized with non-labeled fertilizer. This border application and all other applications of non-labeled ammonium sulfate, were made using a rotary spreader and followed immediately by 5 mm overhead irrigation.

Based on soil analysis, P and K levels were adequate and no supplemental applications were made during the study. No pesticides were applied during the course of the study. Irrigation was applied when neccessary to prevent drought stress. Clippings were collected every seven to ten days during the growing season using a manual hand-held clipper and a vacuum collecter. The mowing height was 40 mm for all sampling dates, and all the clippings were dried at 65°C for 72 hours and stored for later analysis. Prior to analysis, the clippings were ground with a Cyclone Sample Mill (UDY Corporation, Fort Collins, CO).

In order to examine the distribution of fertilizer N in the soil, four microplots from each turf-type were excavated on 17 June, 6 July, and 10 August of 1994 and on 15 June of 1995 for N analysis. These excavation dates corresponded to 2, 21, 56 and 365 days after application of the ^{15}N fertilizer. Each PVC microplot was split longitudinally using a circular saw to expose the soil core within. The microplot cores were then sectioned into verdure and four different soil depths: 0-5 cm (including thatch and/or mat layer), 5-10 cm, 10-20 cm and 20-40 cm. Verdure was removed from the soil core with scissors, dried and processed like clippings prior to N and ^{15}N analysis. After air-drying the 0-5 cm layer, thatch or mat was separated from the soil component by hand massaging. The thatch or mat-sample was ground with a Wiley Mill to pass a 60 mesh screen. Soil from the 0-5 cm layer, as well as subsamples from each of the three remaining depths, were prepared for analysis by pulverizing into fine powder.

For soil, mat, and thatch samples, total N and inorganic N were measured. Inorganic soil nitrogen was determined by extracting duplicate samples of dry soil with 1 M KCl (5:1 v/w). Nitrate-N and ammonium-N were determined by flow injection analysis on a Lachat QuikChem Autoanalyzer (Lachat Instruments, Milwaukee, WI). Following this analysis, inorganic N was converted for ^{15}N analysis by the diffusion method of Brooks et al. (1989). Due to low nitrate and ammonium concentrations, a single diffusion for both N forms was performed and ^{15}N analysis was for inorganic N. For thatch the same procedure was used, however, because of higher N concentrations in thatch, less material was used for the extraction (25:1 v/w). The total N content and the ^{15}N enrichment of clippings, verdure, thatch, soil and all diffusion samples were determined using a Europa Scientific Roboprep C-N Biological Sample Converter and Tracermass mass spectrometer (Europa Scientific USA, Cincinatti, OH). Each sample was analyzed twice. The statistical design was a split-split plot with species representing the main plot, sampling time the sub-plot, and sampling depths the sub-sub-plot (Table 1). The data were analysed statistically using the GLM procedure of SAS (SAS Institute Inc., 1987). The Ryan-Einot-Gabriel-Welsch Multiple range test (REGWQ) was used with a significance level of $p=0.05$.

Results and Discussion

Clipping yield and nitrogen in above-ground biomass

Both clipping yield and N uptake followed a very similar pattern for each species throughout the study (Figure 1), with Kentucky bluegrass giving the best growth in the summer season, and perennial ryegrass in October and November. This may be related to differences in growth pattern, especially in the late fall season. The total yearly clipping yield did not differ between the two species with a Kentucky bluegrass yield of 7680 kg ha^{-1} containing 258 kg N ha^{-1}, while the perennial ryegrass yielded a total of 7850 kg ha^{-1} dry matter (241 kg N ha^{-1}). Nitrogen content in the clippings of Kentucky bluegrass and perennial ryegrass averaged 3.4% and 3.1%, respectively. Corresponding N values in clippings at 21 and 56 DAT were 3.4% and 3.5% for Kentucky bluegrass and 2.7% and 3.1% for perennial ryegrass, indicating a fairly constant N rate in the leaves at different sampling times.

The close relationship between the distributions of dry matter and total N in the clippings, was in agreement with Kentucky bluegrass data reported by Miltner et al. (1996), and perennial ryegrass data from Bristow et al. (1987).

Twenty-five percent of the applied LFN was recovered in the clippings of Kentucky bluegrass 21 DAT (Table 2). At 56 and 365 DAT the cumulative LFN recoveries in Kentucky bluegrass clippings were 38% and 46%, respectively. These findings are somewhat higher than the 30% reported by Starr and DeRoo (1981) in the first 120 days following a May application of $(^{15}NH_4)_2SO_4$, and the 18% and 35% recoveries measured by Miltner et al. (1996) at 31 and 730 days after a ^{15}N-urea application. Hummel and Waddington (1981), however, observed 48% N recovery in clippings of an $(NH_4)_2SO_4$ treated Kentucky bluegrass lawn, indicating that differences in application time, N carrier and yearly N supply may have major impact on N uptake efficiency.

For perennial ryegrass, 21%, 26% and 42% of the applied $(^{15}NH_4)_2SO_4$ was removed at 21, 56, and 365 DAT in this study (Table 2). This was lower than the first-year recoveries reported by Dowdell and Webster (1980) and Bristow et al. (1987), who measured 43-54% and 55% of the applied ^{15}N in perennial ryegrass herbage, respectively. These differences in recoveries may be due to variations in N rates and N sources, as well as different grass use and the less frequent mowing practices typical under pasture conditions.

In the present study, both turfgrass systems showed significantly higher fertilizer N uptake within a short time of application (Figure 2). Uptake of LFN in clippings was rapid during the first three weeks after application with 43% and 51% of total LFN recovery in the aboveground biomass occurring by 21 DAT for perennial ryegrass and Kentucky bluegrass, respectively. From 15 June through 6 July, a mean daily LFN uptake of 0.572 and 0.483 kg ha^{-1} day^{-1} was measured for the bluegrass and ryegrass, respectively. The mean uptake rates dropped to 0.185 for Kentucky bluegrass and 0.069 kg LFN ha^{-1} day^{-1} for perennial ryegrass from 6 July through 10 August. Total N uptake rates for Kentucky bluegrass for the periods of 15 June through 6 July and 7 July through 10 August were 2.267 and 1.986 kg N ha^{-1} day^{-1}, and for perennial ryegrass 1.465 and 0.978 kg N ha^{-1} day^{-1}. Three weeks after the start of fertilization, LFN accounted for 25% of the total N recovered in Kentucky bluegrass clippings. This percentage dropped to 16% at 56 DAT and 9% at 365 DAT. Corresponding values for perennial ryegrass were 33, 19 and 8%. While the LFN uptake dropped markedly throughout the study, total N recovery in the clippings indicated a fairly constant N uptake for both turfgrasses (Table 3), due to frequent applications of non-labeled ammonium sulfate in the growing season and to mineralized N from soil organic matter. A period of unusually high N uptake occured in late August for both species (Figure 1).

The LFN content in the verdure decreased markedly at each sampling time throughout the study for both species (Table 2). Levels of LFN in the verdure of the two species differed only at 2 DAT (Table 4). The decreases in verdure LFN were associated with increases in clipping LFN. This indicates an upward transport of LFN within the shoots from the "stubble" to the removed leaf blades. Except for the first sampling (no clippings were harvested at that time), the amount of shoot (clippings + verdure) LFN did not change significantly throughout the study for either of the two turfgrass species. Between 23.0 and 25.5 kg LFN ha^{-1} were found in Kentucky bluegrass shoots, and 19.3 to 21.1 kg LFN ha^{-1} in perennial ryegrass shoots from 21 to 365 DAT. Expressed in percentages of the total LFN applied, 47 to 52% of total LFN was recovered in the shoots of Kentucky bluegrass, and 40 to 43% in the shoots of perennial ryegrass. These values are similar to the 39% recovery reported by Miltner et al. (1996) in spring-urea treated Kentucky bluegrass plots.

Nitrogen in thatch/mat

The amounts of LFN and total N in thatch and/or mat were different between the two turfgrass systems at each sampling date, except at 56 DAT (Table 4), mainly due to differences in the thatch/mat organic matter content. The upper 0-5 cm layer was on average 8% thatch organic matter by dry weight for Kentucky bluegrass samples, and the corresponding value for perennial ryegrass mat was 2% (data not shown). Even though the mean total N content in Kentucky bluegrass thatch (237 kg ha^{-1}) was twice the amount measured in perennial ryegrass mat (mean of 119 kg N ha^{-1}), the latter was found to be an important sink for fertilizer N as well.

The level of LFN and total N in Kentucky bluegrass thatch and perennial ryegrass mat showed significant fluctuations within the experimental period (Tables 2 and 3). While the total N content of both species followed the same trend throughout the experiment, a major difference was observed for LFN recovery at the final sampling of Kentucky bluegrass. Thirty-eight percent of the applied LFN was recovered in Kentucky bluegrass thatch on 17 June (2 DAT). This level dropped to about 13% at 6 July (21 DAT) and 12% at 10 August (56 DAT). The decreases in thatch LFN in July and August were related, in part, to increases in the amount recovered in clippings, indicating mineralization and transport of LFN from the thatch upwards to the shoot tissue. No increase in soil LFN was observed at the same time, indicating that downward transport of mineralized thatch LFN is not a significant process. Approximately 20% of the LFN applied was found in the Kentucky bluegrass thatch at 365 DAT. A significant increase in Kentucky bluegrass thatch N content and yield from 10 August (56 DAT) to 15 June (365 DAT), probably due to lower decomposition rate of organic matter and to increased rates of rhizome development under late summer/fall and spring conditions, may explain the increase in LFN and total N immobilization within this period. The total thatch LFN recovery after one year (20%) was similar to the 21% reported by Starr and DeRoo (1981), but unlike the LFN recovery (30-35%) presented by Miltner et al. (1996).

About 28% of the applied LFN was recovered in perennial ryegrass mat at 17 June (2 DAT). This LFN level dropped to 11% over the next two months, and remained relatively constant through the last sampling date (Table 2). A combination of different growth patterns, and lower microbial activity in mat than thatch, may explain some of the differences in LFN and total N immobilization for the two turfgrass species.

Total N and LFN in Kentucky bluegrass thatch and perennial ryegrass mat were predominantly in organic forms (data not shown). Less than 0.2% of the total LFN, and < 0.1% of the total N, were in the inorganic pool for the two turfgrass species. The separation technique of thatch and mat organic matter from the soil fraction by hand-massaging may not remove all the mineral particles, giving a small percentage of ammonium nitrogen in the samples.

Nitrogen in soil

Total N and LFN amounts in soil were slightly higher in perennial ryegrass than Kentucky bluegrass (Tables 2 and 3). No significant differences were found in soil LFN between 2 and 56 DAT, but between 56 and 365 DAT soil LFN decreased significantly, particularly in the upper 5 cm. Mineralization of LFN in the soil and upward transport to the thatch/mat or shoot tissue accounted for about one-half of the decrease in soil LFN. The rest of the decrease in LFN recovery is attributable to either gaseous losses or experimental error.

Between 21% and 27% of the total LFN applied was found in perennial ryegrass soil at 2 and 56 DAT, respectively. By 15 June (365 DAT) only 14% was recovered from the soil. For Kentucky bluegrass, 20%, 14%, 16% and 9% was recovered as soil LFN at 2, 21, 56, and 365 DAT, respectively. This decreasing LFN recovery over time is similar to the values presented by Power and Legg (1984), but they differ with the findings of Miltner et al. (1996) who found 8% of the LFN recovered from soil at 18 DAT, and 14% two years later. The total LFN recoveries found in the soils at the end of present study were similar to the value of 14% reported by Starr and DeRoo (1981) and the 13% to 17% noted by Watson (1987) at 120 and 49 days from the last ^{15}N treatment.

Because soil LFN did not significantly change below 5 cm, and the total LFN recovery decreased over time, gaseous losses is the most likely reason for these results. Some downward LFN transport may have occurred particularly for the ryegrass plots (Table 2), however, this seems to be more related to N transport in soil macropores a short time after application, than downward leaching of N throughout the study. Soil N decreased markedly from August 1994 to June 1995 at both turfgrass sites. As mentioned earlier, this may be related to mineralization.

Soil LFN occurred primarily in the organic pool (Table 5). Two days after application only 2.8% (0.59 $\mu g\ g^{-1}$) of the total LFN concentrations in Kentucky bluegrass soil was found in the inorganic pool. Within a year of sampling this fraction dropped to 0.4% (0.06 $\mu g\ g^{-1}$).

Almost identical results were obtained from perennial ryegrass plots, showing that 3.2% and 0.7% of the LFN concentrations was presented in the inorganic N pool at 2 and 365 DAT, respectively. These results are supported by Bowman et al. (1989) who reported that inorganic N is depleted in 2 to 4 days and that the depletion primarily is a result of biological immobilization.

Mass balance

In a turfgrass system nitrogen may be found as ammonium- and nitrate-N in the soil, and as organic N in both the soil and the turfgrass plant. Using ^{15}N-labeled $(NH_4)_2SO_4$ allows one to distinguish fertilizer N from nitrogen already present in plants and soil, and to more precisely follow the distribution and cycling of N in different parts of the turf system.

Recoveries of LFN in different pools indicate that a significant part of the LFN was taken up by the roots and transported to the turfgrass shoots within 2 DAT, 34% (16.4 kg ha^{-1}) for Kentucky bluegrass and 25% (12.0 kg ha^{-1}) for perennial ryegrass, respectively (Table 2). In addition, as much as 38% (Kentucky bluegrass) and 28% (perennial ryegrass) of the applied fertilizer N was immobilized in the thatch or mat layer at the same time.

The distribution and cycling of LFN in plant material remained fairly constant throughout the study. Between 63% and 72% of the LFN applied to Kentucky bluegrass, and 51% to 55% of the LFN applied to perennial ryegrass plots, was recovered in shoots plus thatch or mat organic matter at each sampling date. The results also showed that the cumulative recovery of LFN in clippings at each sampling date increased and recovery in verdure decreased correspondingly for both turfgrasses, indicating a very similar cycling of LFN within the shoots of these two species. The large decrease in Kentucky bluegrass thatch LFN between 2 and 21 DAT was not compensated with an equivalent LFN increase in the shoots or soil, but rather coincided with a decrease in total recovery. The decrease in mat LFN, however, was associated with a corresponding increase in LFN in the aboveground plant tissue.

The soil LFN showed minor fluctations during the summer, averaging 17% for Kentucky bluegrass and 24% for perennial ryegrass. A significant drop in the soil LFN content was observed from 56 to 365 DAT, and may be related to mineralization in the upper 0-5 cm. In bluegrass, about one-half of the mineralized soil N appeared to be taken up by the thatch, and the remainder may have been lost as gas, indicating that the thatch layer was acting as both a significant sink and a source for fertilizer N. For the perennial ryegrass plots, the reduction in soil LFN was closely related to a decrease in the total LFN recovery.

Even though leaching losses were not measured, it is reasonable to believe that leaching did not play any significant role in the mass balance constructions. Very small LFN concentrations were found in the 20-40 cm soil layer for both turfgrass systems, and the data presented does not implicate downward leaching as a major pathway for N loss. However, there is evidence of some downward movement of ^{15}N, particularly in the ryegrass plots between 10 August 1994 and 15 June 1995 (Table 2).

The total recovery of LFN in Kentucky bluegrass varied from 77% to 91%. This was slightly higher than the total LFN recovery found for perennial ryegrass (67 to 79%). Compared to other ^{15}N experiments, the total LFN recovery in the present study was similar to the 60 to 84% recovery reported by Starr and DeRoo (1981), Bristow et al. (1987) and Miltner et al. (1996), but it was higher than the 43% to 54% recovery reported by Dowdell and Webster (1980). In the present study, the highest recoveries were measured at 2 DAT, and the lowest at 365 DAT. This may reflect loss of LFN as gas at different times throughout the study for both turf systems, as also concluded by the authors mentioned above. Another possible source of the variation in the total LFN recoveries may be, as also reported by Miltner et al. (1996), that different microplots were sampled at each sampling date.

Table 4 shows a comparision of LFN amounts in various pools for Kentucky bluegrass and perennial ryegrass at different sampling dates. Significantly higher LFN recoveries were found in verdure and thatch of bluegrass at 2 DAT, than found for ryegrass, indicating that the thatch can tie up more fertilizer N than the mat, and that part of the LFN is likely to be transported upwards to the shoots quickly. Still more LFN was retained within the thatch than within the mat layer at 365 days after treatment, which means that the thatch is a significantly larger N sink than the mat-layer.

Acknowledgements

The authors wish to thank Prof. Don Christenson and Prof. Darryl Warncke for allowing us to use their laboratory and equipment for soil and plant preparations, Dave Harris for running the diffusion samples and Prof. Bal Ram Singh for useful comments on the manuscript. Technical assistance from Brian Horgan, Ron Calhoun and Prof. Antoni Szafranek is gratefully acknowledged.

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Table 1. GLM table for total nitrogen and labeled fertilizer nitrogen (LFN) recovered in Kentucky bluegrass and perennial ryegrass treatments.

		Nitrogen		LFN	
Source	DF1)	Mean Square	F	Mean Square	F
Replication	3	18411.81	4.62 **	1.68	3.34 *
Specie	1	1192850.71	18.01 *	26.22	21.97 *
Error A (Specie*Rep)	3	66242.28		1.19	
Depth	6	13373033.60	368.84 ***	1531.38	442.05 ***
Specie*Depth	6	762878.75	21.04 ***	55.86	16.12 ***
Error B (Specie*Rep*Depth)	36	36257.46		3.46	
Time	3	942244.05	8.97 **	16.37	8.45 **
Error C (Time*Rep)	9	105061.61		1.94	
Specie*Time	3	153057.47	1.85 ns	3.31	1.01 ns
Error D (Specie*Time*Rep)	9	82705.48		3.26	
Time*Depth	18	310796.04	3.51 ***	375.80	120.16 ***
Specie*Time*Depth	18	205328.34	2.32 **	11.15	3.56 ***
Error E (Specie*Time*Rep*Depth)	108	88551.36		3.13	

1) degrees of freedom

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$; ns = not significant.

Table 2. Recovery of labeled fertilizer nitrogen (LFN) in various "depths" and total percent recovery at each sampling date for the Kentucky bluegrass and perennial ryegrass plots.

Specie	Date	Clippings	Verdure	Thatch/mat	0-5 cm	5-10 cm	10-20 cm	20-40 cm	Total[1]	Recovery (%)
		kg LFN ha^{-1}								
Kentucky bluegrass	6/17/94	0	16.37 a	18.51 a	8.83 a	0.42 b	0.20 a	0.29 a	44.62	91
	7/6/94	12.01 a[2]	12.67 b	6.31 c	6.64 a	0.24 b	0.04 b	0 b	37.91	78
	8/10/94	18.49 b	7.00 c	5.74 c	7.52 a	0.48 b	0.03 b	0 b	39.26	80
	6/15/95	22.26 c	0.81 d	10.01 b	3.29 b	0.83 a	0.15 ab	0 b	37.35	77
Perennial ryegrass	6/17/94	0	11.96 a	13.48 a	11.09 a	1.08 a	0.59 a	0.23 a	38.43	79
	7/6/94	10.15 a	10.97 a	5.47 b	8.91 a	0.81 a	0.44 a	0.24 a	36.99	76
	8/10/94	12.55 b	6.77 b	5.56 b	10.90 a	0.81 a	0.46 a	0 b	37.05	76
	6/15/95	20.37 c	0.71 c	4.75 b	5.40 b	0.91 a	0.48 a	0.07 a	32.69	67

1) 48.8 kg N ha^{-1} applied on 15 June 1994.

2) Means with the same letter within a coloumn for each species are not significantly different at p=0.05. For clippings the amounts recovered within each period, and not the cumulative values, are used.

Table 3. Recovery of total nitrogen in various "depths" for the Kentucky bluegrass and perennial ryegrass plots.

Specie	Date	Clippings	Verdure	Thatch/mat	0-5 cm	5-10 cm	10-20 cm	20-40 cm	Total
		kg N ha^{-1}							
Kentucky bluegrass	6/17/94	0	104 a	257 b	944 a	887 b	918 ab	558 c	3668
	7/6/94	48 a[1]	89 b	154 c	801 a	750 c	1042 a	997 a	3880
	8/10/94	117 b	88 b	160 c	841 a	1007 a	1123 a	1109 a	4446
	6/15/95	258 c	63 c	376 a	394 b	579 d	679 b	749 b	3097
Perennial ryegrass	6/17/94	0	61 ab	140 a	929 b	895 a	1195 ab	1911 a	5131
	7/6/94	31 a	65 ab	88 b	1032 ab	776 b	1134 b	1120 b	4245
	8/10/94	65 b	69 a	98 b	1139 a	936 a	1316 a	1529 ab	5152
	6/15/95	241 c	54 b	150 a	553 c	624 c	851 c	987 b	3460

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[1] Means with the same letter within a coloumn for each species are not significantly different at $p=0.05$. For clippings the amounts recovered within each period, and not the cumulative values, are used.

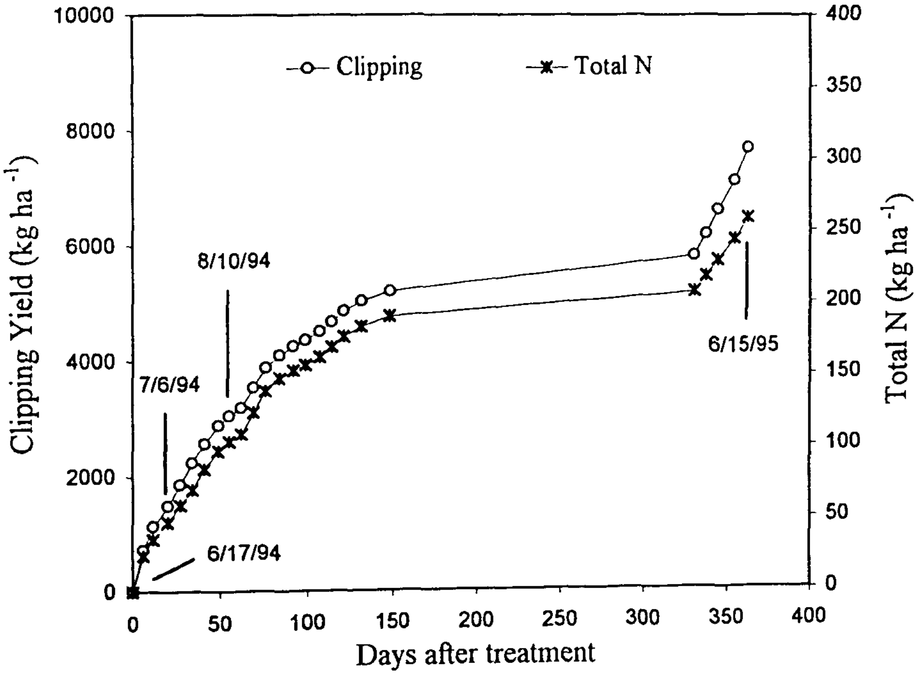
Table 4. Recovery of labeled fertilizer nitrogen in each "depth" at 2, 21, 56 and 365 days after treatment (DAT) for the Kentucky bluegrass (KB) and perennial ryegrass (PR) plots.

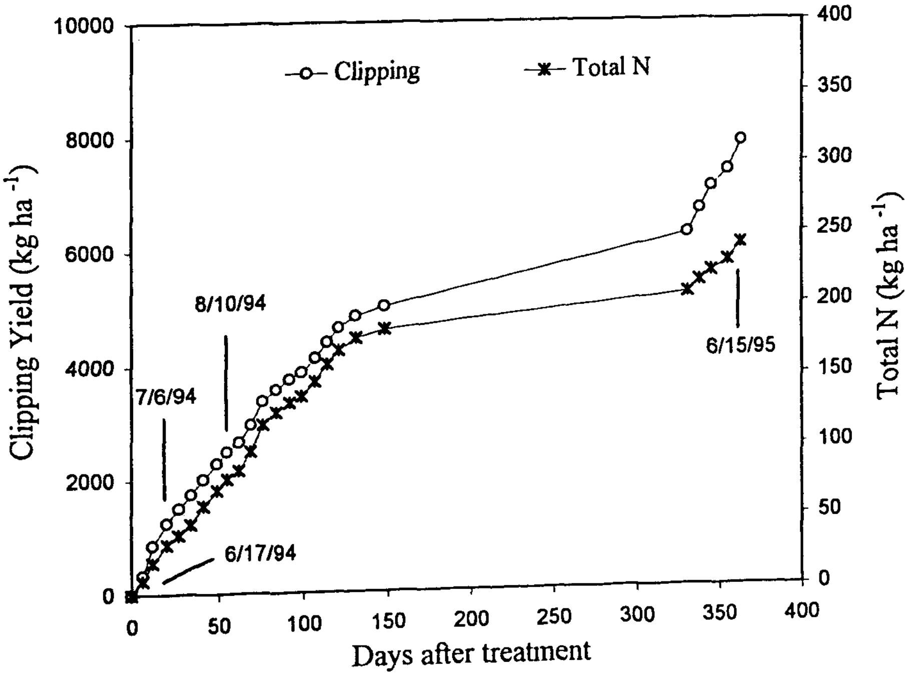
Date	DAT	"Depth"	Treatment KB	Treatment PR
			kg LFN ha^{-1}	kg LFN ha^{-1}
6/17/94	2	Clippings	0	0
		Verdure	16.37 a	11.96 b
		Thatch/mat	18.51 a	13.48 b
		Soil (0-5 cm)	8.83 a	11.09 a
		Soil (5-10 cm)	0.42 b	1.08 a
		Soil (10-20 cm)	0.20 b	0.59 a
		Soil (20-40 cm)	0.29 a	0.23 a
		TOTAL	44.62	38.43
7/6/94	21	Clippings	12.01 a	10.15 b
		Verdure	12.67 a	10.97 a
		Thatch/mat	6.31 a	5.47 b
		Soil (0-5 cm)	6.64 a	8.91 a
		Soil (5-10 cm)	0.24 b	0.81 a
		Soil (10-20 cm)	0.04 b	0.44 a
		Soil (20-40 cm)	0 b	0.24 a
		TOTAL	37.91	36.99
8/10/94	56	Clippings	18.49 a	12.55 b
		Verdure	7.00 a	6.77 a
		Thatch/mat	5.74 a	5.56 a
		Soil (0-5 cm)	7.52 b	10.90 a
		Soil (5-10 cm)	0.48 a	0.81 a
		Soil (10-20 cm)	0.03 b	0.46 a
		Soil (20-40 cm)	0 a	0 a
		TOTAL	39.26	37.05
6/15/95	365	Clippings	22.26 a	20.37 a
		Verdure	0.81 a	0.71 a
		Thatch/mat	10.01 a	4.75 b
		Soil (0-5 cm)	3.29 b	5.40 a
		Soil (5-10 cm)	0.83 a	0.91 a
		Soil (10-20 cm)	0.15 b	0.48 a
		Soil (20-40 cm)	0 a	0.07 a
		TOTAL	37.35	32.69

Means with the same letter within a row are not significantly different at $p=0.05$.

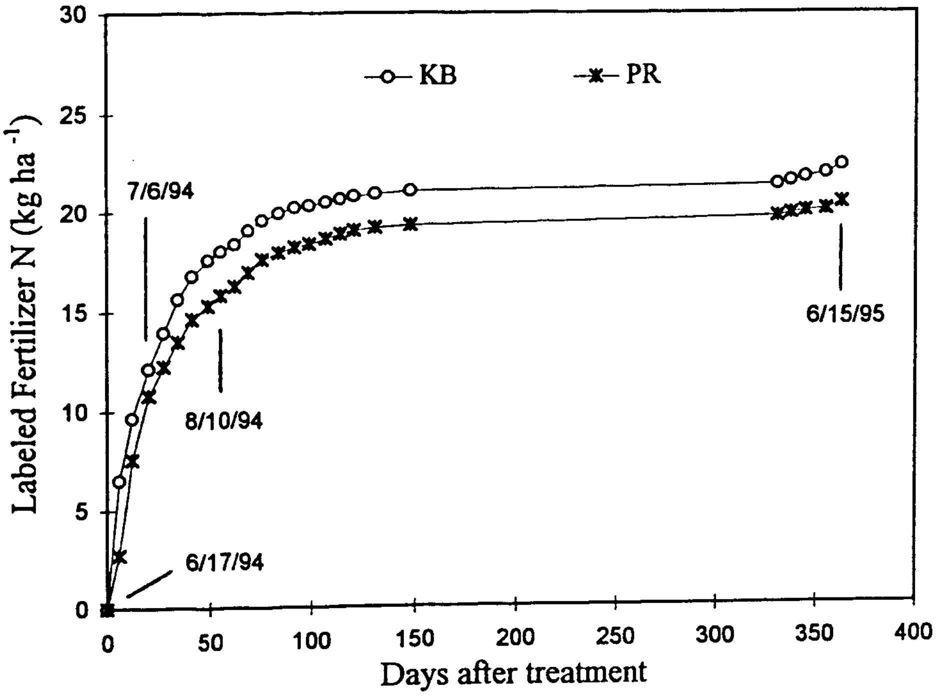
Table 5. Recovery of soil inorganic, soil organic, and total soil LFN concentrations by various depths for each sampling date for Kentucky bluegrass and perennial ryegrass.

Date	Depth (cm)	Kentucky bluegrass Inorganic	Kentucky bluegrass Organic	Kentucky bluegrass Total	Perennial ryegrass Inorganic	Perennial ryegrass Organic	Perennial ryegrass Total
			$\mu g\ g^{-1}$			$\mu g\ g^{-1}$	
6/17/94	0-5	0.54	19.52	20.06	0.53	16.40	16.93
	5-10	0.03	0.44	0.47	0.03	1.12	1.15
	10-20	0.02	0.09	0.11	0.02	0.34	0.36
	20-40	0	0.10	0.10	0.01	0.06	0.07
7/6/94	0-5	0.28	15.02	15.30	0.18	12.03	12.21
	5-10	0.02	0.26	0.28	0.03	0.93	0.96
	10-20	0.01	0.01	0.02	0.01	0.26	0.27
	20-40	0	0	0	0	0.09	0.09
8/10/94	0-5	0.08	22.35	22.43	0.10	14.52	14.62
	5-10	0.03	0.43	0.46	0.03	0.77	0.80
	10-20	0.01	0	0.01	0.02	0.24	0.26
	20-40	0	0	0	0	0	0
6/15/95	0-5	0.03	14.37	14.40	0.04	12.15	12.19
	5-10	0.02	0.96	0.98	0.03	1.10	1.13
	10-20	0.01	0.08	0.09	0.02	0.30	0.32
	20-40	0	0	0	0.01	0.02	0.03





Figur 1. Cumulative clipping yield and total N harvested in clippings from Kentucky bluegrass (upper) and perennial ryegrass microplots (lower) from 15 June 1994 to 15 June 1995.



Figur 2. Cumulative labeled fertilizer nitrogen (LFN) harvested in Kentucky bluegrass (KB) and perennial ryegrass (PR) clippings from 15 June 1994 to 15 June 1995.