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Clipping Contributions To Nitrate Leaching From Creeping Bentgrass Under Varying Irrigation And N Rates

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ABSTRACT

The effect of clipping management on nitrate (NO_3) leaching beneath creeping bentgrass (*Agrostis stolonifera* L.) has received little attention. The objective of this experiment was to examine the effects of returning grass clippings to creeping bentgrass in combination with N fertilization and irrigation on NO_3 leaching. A 30-week long experiment was conducted using fairway-height creeping bentgrass in large, undisturbed soil columns (20.3-cm diam. x 60.9-cm length) under controlled greenhouse conditions. Treatments were four rates of N fertilization (equivalent to 0, 98, 196, and 392 kg N ha^{-1} $year^{-1}$) and two levels of irrigation [standard (25 mm per week) or standard + historical weekly precipitation amounts], with grass clippings either returned or removed. Higher percolate NO_3-N concentrations and mass losses were found when clippings were returned, as N rate increased, and with the higher irrigation treatment. Flow-weighted concentrations of NO_3-N in percolate ranged from 0.13 to 21.0 mg L^{-1} and the percent of applied N lost as leachate ranged from 0.9 to 63%. These findings suggest that water quality goals may not be reached if N fertilization rates are not reduced when clippings are returned to bentgrass fairways or in cases of over-watering.

Abbreviations

CRM, clippings removed; CRT, clippings returned; S, standard irrigation rate; S+P, standard irrigation rate + precipitation

Keywords

clipping management, fairway management, nitrate fertilization, over-watering

INTRODUCTION

The fate of nitrogenous fertilizers applied to turfgrass has come under scrutiny because of its potential for negative environmental impacts. Petrovic (1990) presented a review of the fate of nitrogenous fertilizers applied to turfgrass and examined the status of research on NO_3 leaching. Based on this review, factors that influenced NO_3 leaching from turf were N source and rate, soil type, irrigation and season of application. The amount of NO_3 leaching was found to be highly variable, ranging from 0 to 80% loss of applied N.

Clipping return was not cited as a factor influencing NO_3 leaching, however, the effect of returning clippings to turfgrass on NO_3 leaching was only addressed by one reviewed study (Starr and DeRoo, 1981). Clipping return has the potential to effect NO_3 leaching, though, since turfgrass clippings may contain relatively high concentrations of NO_3-N which is readily released as the clippings decompose (Kopp and Guillard, 2004).

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Starr and DeRoo (1981) performed a mass balance study of the fate of ^{15}N fertilizer applied to a mixed species stand of Kentucky bluegrass (*Poa pratensis* L.) and creeping red fescue (*Festuca rubra* L.). Grass clippings were removed from two of the plots and returned to the other two plots. Suction lysimeters were used to sample soil water from the saturated zone beneath the turf plots (180 to 240-cm depths). Nitrate-N concentrations ranging from 0.3 to 10 mg L^{-1} were observed during the 3-year study. When clippings were returned, NO_3-N concentration averaged 2.0 mg L^{-1} and when clippings were removed, NO_3-N concentration averaged 1.9 mg L^{-1}. Samples from ground water wells 25 and 50 m upstream from the experimental plots averaged 0.9 and 2.7 mg NO_3-N L^{-1}, respectively. Based on these data, Starr and DeRoo concluded that clipping management had little, if any, effect on leaching loss of NO_3-N from the turfgrass plots.

Other studies have also examined the effects of returning clippings to turfgrass. In a study that utilized a mulching mower, Heckman et al. (2000) returned clippings to a Kentucky bluegrass lawn. Returning grass clippings was found to improve the color of the turf and reducing N fertilization by 50% did not diminish turfgrass color when clippings were returned (Heckman et al., 2000). It was also found, in the study, that potential turfgrass quality problems related to surge growth and unsightly clippings were lessened by the use of slow-release fertilizers.

Though fertilization is a primary contributor to turfgrass nutrient leaching, irrigation rates are also of concern. Morton et al. (1988) performed a study in which Kentucky bluegrass turf was subjected to three levels of N fertilization (0, 97, and 244 kg N ha^{-1} $year^{-1}$) and two irrigation schedules (tensiometer-scheduled or 38 mm per week + precipitation). Over-watering, in combination with N fertilization, was found to generate significantly higher annual flow-weighted concentrations and mass loss than unfertilized controls. Nevertheless, seasonal and annual flow-weighted concentrations were always less than half the United States Environmental Protection Agency's (USEPA) drinking water standard of 10 mg NO_3-N L^{-1}. Morton et al. (1988) concluded that leaching losses from home lawns did not pose a threat to drinking water aquifers. However, it has been suggested that drainage from home lawns in coastal watersheds may contribute to the degradation of bay and estuarine water quality at concentrations much less than 10 mg NO_3-N L^{-1} (Ryther and Dunstan, 1971).

The effects of N fertilization and irrigation on turfgrass nutrient leaching have also been examined in bentgrass. The percentage of applied N found to leach in bentgrass studies ranged from <0.5% to 38% of N applied and the NO_3-N concentrations of percolate ranged from 0.14 mg L^{-1} to 68.8 mg L^{-1} (Bowman et al., 1998; Huang and Petrovic, 1994; Mancino and Troll, 1990). In addition to fertilization rates and irrigation levels, the use of amendments, such as clinoptilolite zeolite, rooting architecture, and fertilizer sources affected nutrient leaching in bentgrass (Bowman et al., 1998; Huang and Petrovic, 1994; Mancino and Troll, 1990).

The question of whether or not NO_3-N leaching from turfgrass poses an environmental risk remains unanswered as evidenced by the wide range of applied fertilizer N losses (0 to 95%) reported in the literature. It is clear that NO_3 leaching losses may be minimized by certain management techniques. However, the effects of returning grass clippings to turfgrass, a practice that is likely to increase in the United States, on the leaching of NO_3 from turf have received little attention. A study was therefore undertaken to determine the combined effects of clipping management, irrigation, and N fertilizer rate on nitrate leaching from creeping bentgrass.

MATERIALS AND METHODS

A soil column experiment was conducted under greenhouse conditions at the University of Connecticut's Plant Science Research and Teaching Farm in Storrs, Connecticut, USA. The experiment was arranged in a 4 x 2 x 2 factorial set out in a randomized complete block design with four replicates. Experimental treatments were four rates of N fertilization in three split applications (equivalent to 0, 98, 196, or 392 kg N ha^{-1}), two clipping treatments (returned or removed), and two irrigation treatments (standard irrigation or standard irrigation + precipitation). The standard irrigation + precipitation (S+P) treatment was equal to the weekly rainfall amounts of the 1989 growing season (Storrs) plus a standard irrigation amount of 25 mm per week. Precipitation during the growing season of 1989 was the greatest amount of the previous thirty years and the S+P treatment was designed to simulate a worst-case scenario in terms of leaching.

Sixty-four undisturbed soil columns were collected from a sod farm in Wethersfield, Connecticut, USA. The soil at the site was an Agawam fine sandy loam composed of 60% sand, 30% silt, and 10% clay (coarse-loamy over sandy, mixed, active, mesic Typic Dystrudept) (Agency for International Development, 1992). Schedule 40, polyvinylchloride (PVC) pipe was cut into 64 columns measuring 20.3-cm in diameter and 76.2-cm in length. One end of each column was beveled to a 45° angle to facilitate pressing into the soil. The columns were pushed into bare soil using the bucket of a tractor with a front-end loader until approximately 3 cm of PVC pipe remained above ground. Once all of the columns had been pressed into the ground, trenches were dug around them and they were broken off at the base. Both ends of the columns were wrapped in plastic to prevent desiccation and they were transported to the greenhouse.

In the greenhouse, four wooden frames were constructed on four greenhouse benches to hold the soil columns. High-density polyethylene (HDPE) funnels were placed in the base of the wooden frames to support the columns. Funnels were lined with glass fabric and then filled with pea stone to support the soil in the columns. Glass fabric was also placed between the soil at the base of the columns and the pea stone to prevent soil loss. Flexible PVC tubing (2.54-cm inner diam.) was run from the funnel outlets to collection vessels beneath the columns. Low-density polyethylene (LDPE) containers of 1 or 3.8 L, depending upon irrigation treatment, were used as collection vessels for column effluent. A two-zone (standard and S+P), automated irrigation system was arranged using drip stakes (1.44 L per hr) to irrigate the soil columns. Because the experiment was begun during the later part of the natural growing season, high-pressure sodium lights were used to extend day length to 16 hr per d until natural daylight was sufficient for active turfgrass growth. Approximate light intensity was 90 to 100 μmol m^{-2} s^{-1} of photosynthetically active radiation (PAR). Daytime greenhouse temperatures were set at 21 °C and nighttime temperatures were set at 13 °C.

The columns were seeded with 'Providence' creeping bentgrass and irrigation was applied at a rate of 25 mm per week. The grass was allowed to establish for 6 months prior to the application of the experimental treatments. Experimental data were collected for 30 weeks. During week 1, experimental irrigation treatments were started and the first fertilization took place. Reagent grade NH_4NO_3 was dissolved in deionized water, and applied to

Table 1. Thirty-year normal rainfall amounts (Storrs, Connecticut, USA) and standard irrigation rates + precipitation totals for the experimental period.

Month	30-yr Normal Rainfall	Standard + precipitation†
	mm	
1	102	188
2	100	299
3	112	301
4	108	225
5	112	358
6	118	170
7	116	203

† Standard + precipitation treatment was equal to the weekly rainfall amounts during the 1989 growing season (Storrs) plus 25 mm of water per week.

Precipitation during the growing season of 1989 was the greatest amount of the previous thirty years.

Table 2. Summary of analyses of variance indicating significant source effects for percolate flow-weighted NO_3-N concentration and cumulative mass loss NO_3-N from creeping bentgrass-covered soil columns under varying N rates, clipping treatments, and irrigation rates.

Source	df	Mean Squares	
		NO_3-N Concentration	Mass Loss NO_3-N
N Rate (N)	3	***	***
Clipping (C)	1	***	***
N × C	3	**	*
Irrigation (I)	1	*	***
N × I	3	NS	***
C × I	1	**	NS
N × C × I	3	*	NS
Error	45		

*,**,***, NS Significant at $P < 0.05, 0.01, 0.001$, and not significant ($P > 0.05$), respectively.

the columns to provide 0, 98, 196 or 392 kg N ha^{-1} in three split applications (at weeks 1, 12, and 22). In addition, K and P were applied at rates of 41 kg K and 21 kg P ha^{-1}. Cutting height was 13 mm, which would be appropriate for golf fairway conditions.

Percolate samples were collected weekly and the volume was determined. Subsamples of the percolate (25 to 50 ml) were taken to the laboratory for immediate analysis. Percolate samples were analyzed for NO_3-N concentrations on a Scientific Instruments Continuous Flow Analysis System (WESTCO, Danbury, CT) using a Cd-reduction, colorimetric method. During the first two months of the experiment, percolate samples were also analyzed for concentrations of NH_4-N. The analysis was discontinued, however, because NH_4-N was not detected in the percolate during that time. When NO_3-N concentrations were below the detection limit of 0.05 mg L^{-1} (37% of samples), a value of 0.025 mg L^{-1} was substituted for the purposes of statistical analyses. The mass of NO_3-N leached was calculated as the concentration of NO_3-N x percolate volume. Flow-weighted NO_3-N concentrations were calculated as the total mass of NO_3-N leached divided by the total volume of percolate collected. Percentage of applied N lost by leaching was calculated after subtracting losses from the unfertilized control.

The effects of fertilization rate, clipping treatment, irrigation rate, and their interactions upon cumulative mass of NO_3 leached and flow-weighted NO_3 concentration were determined using the SAS procedure MIXED (SAS, 1999). Prior to statistical analysis, flow-weighted concentrations and mass loss data were subjected to a square-root transformation as suggested by a simplified method of the Box-Cox power transformation (Box et al., 1978). For data presentation, transformed means were converted back to the original scale.

RESULTS

Monthly irrigation amounts in relation to 30-year normal precipitation values for Storrs, Connecticut, USA are presented in Table 1. Standard irrigation (25 mm per week) closely matched 30-year normal values while S+P exceeded normal values by 50 to 250 mm, depending on month. The average coefficient of variation of weekly leachate collection volumes from the soil columns was 11.8%. The average occurrence of inadequate sampling amounts for collection was 1.2%.

Nitrate-Nitrogen Concentration

Significant effects ($P < 0.01$) upon flow-weighted NO_3-N concentration were attributed to N rate, clipping treatment, irrigation treatment, and irrigation x clipping treatment, N rate x clipping treatment, and irrigation x clipping x N rate interactions (Table 2). Peak, non flow-weighted percolate NO_3-N concentrations were higher when clippings were returned (CRT) for both irrigation treatments (Fig. 1A-D). Highest percolate NO_3-N concentrations were observed at the highest N rate (392 N) and irrigation level (S+P) when clippings were returned (CRT) (Fig. 1D). Delays were observed between the time of fertilization and the appearance of associated peak NO_3-N concentrations. These delays were particularly apparent for the S+P/CRM (clippings removed) and CRT

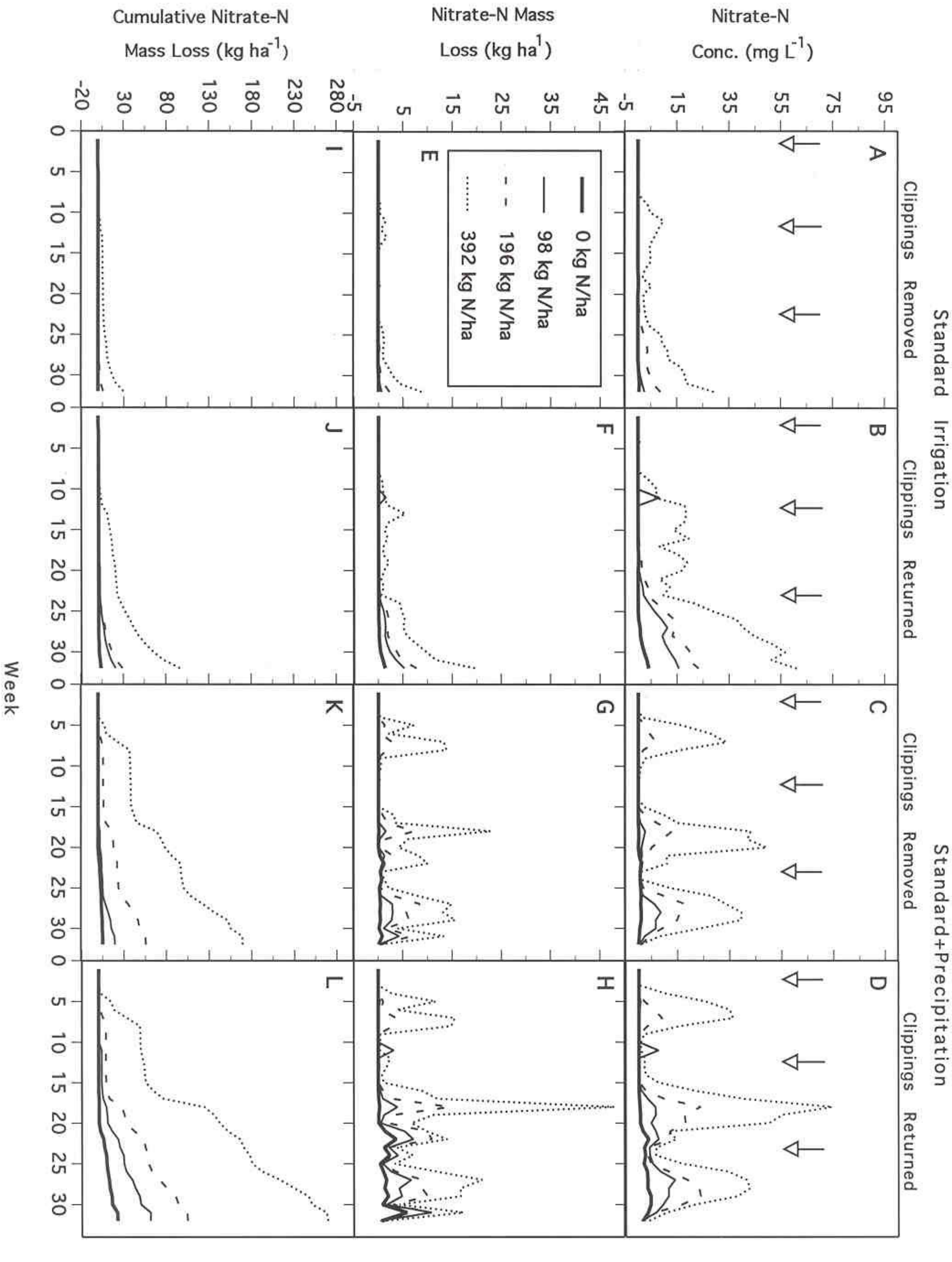

Figure 1. Concentration of NO_3-N in percolate (A-D), NO_3-N mass in percolate (E-H), and cumulative NO_3-N mass in percolate across experimental treatments (I-L). Arrows indicate dates of fertilization.

Table 3. Percolate flow-weighted NO_3-N concentrations from creeping bentgrass-covered soil columns under varying N rates, clipping treatments, and irrigation rates.

	Standard		Standard + Precipitation	
N Rate	CRM†	CRT‡	CRM	CRT
kg N ha^{-1}	mg L^{-1}			
0	0.13	0.71	0.32	1.44
98	0.40	4.44	1.34	4.03
196	1.49	6.41	3.78	6.87
392	7.72	21.0	11.8	16.8
Linear	***	***	***	***
Quadratic	*	NS	NS	NS
Cubic	NS	*	NS	NS

†CRM-clippings removed.

‡CRT-Clippings returned.

*, ***, NS Significant at $P < 0.05$, 0.001 and not significant ($P > 0.05$), respectively.

Table 5. Percentage loss of applied fertilizer N from creeping bentgrass-covered soil columns under varying N rates, clipping treatments, and irrigation rates.

	Percentage Loss of Applied N			
	Standard irrigation		Standard irrigation + Precipitation	
N Rate	CRM	CRT	CRM	CRT
kg N ha^{-1}	%			
98	0.9	17.2	14.3	39.2
196	2.8	12.8	25.8	41.8
392	7.6	23.6	41.8	62.9

(clippings returned) treatments. There was a five-week delay before peak NO_3-N concentration was observed after fertilization #1 (Fig. 1C,D). There were six to eight-week delays until peak NO_3-N concentrations were observed after fertilization #2 and five to seven-week delays after fertilization #3 (Fig. 1C,D).

Flow-weighted NO_3-N concentration increased with N rate, when clippings were returned, and, in most cases, at the higher irrigation rate (Table 3). The highest flow-weighted NO_3-N concentration was observed at the 392 N-CRT / standard irrigation treatment followed by the 392 N-CRT / S+P treatment (Table 3).

Nitrate-Nitrogen Mass Loss

Significant source effects on cumulative mass loss were attributed to irrigation treatment, N rate, clipping treatment, irrigation treatment ´ N rate, and N rate ´ clipping treatment (Table 2). Peak NO_3-N concentrations and mass losses were observed at the 392 N-CRT treatments followed by the 392 N-CRM treatments (Fig. 1E-H). In addition, S+P cumulative NO_3-N mass losses were generally higher than standard irrigation rate observations (Fig. 1I-L). Cumulative NO_3-N mass losses increased with N rate, when clippings were returned, and

Table 4. Cumulative NO_3-N mass losses from creeping bentgrass-covered soil columns under varying N rates, clipping treatments, and irrigation rates.

	Clipping Management		Irrigation	
N Rate	Removed	Returned	Standard	Standard + Precipitation
kg N ha^{-1}	mg L^{-1}			
0	1.9	10.1	1.4	11.2
98	7.8	37.3	7.9	37.2
196	23.8	60.2	14.2	78.3
392	85.4	171	57.5	217
Linear	***	***	***	***
Quadratic	NS	NS	NS	NS
Cubic	NS	NS	NS	NS

***, NS Significant at $P < 0.001$ and not significant, respectively.

at the higher irrigation rate (Table 4). The highest mass losses were observed with the 392 N / S+P treatment followed by the 392 N-CRT treatment (Table 4).

Percentage mass losses by leaching of applied N (corrected for control) when clippings were removed ranged from 0.9 to 7.6% for the standard irrigation treatment and from 14.3 to 41.8% for the S+P treatment (Table 5). When clippings were returned, percentage mass losses of N applied ranged from 12.8 to 23.6% for the standard irrigation treatment and from 39.2 to 62.9% for the S+P treatment. In both cases, mass loss increased with the S+P treatment and the CRT treatment.

DISCUSSION

Our data clearly show that the return of clippings to creeping bentgrass can increase NO_3-N concentration and mass loss in percolating soil water. We found one other study that examined the effect of returning grass clippings to turfgrass on NO_3-N leaching. After applying 195 kg N ha^{-1} year^{-1} or 180 kg N ha^{-1} year^{-1} to a Kentucky bluegrass-creeping red fescue turf for three years, Starr and DeRoo (1981) concluded that NO_3-N leaching losses were negligible regardless of clipping management. Nitrate-N concentrations ranged from 0.3 to 10 mg L^{-1} during their study. Average concentrations were 2.0 and 1.9 mg L^{-1} from clippings returned and removed plots, respectively. They did not find any difference in soil water NO_3-N concentration between returning and removing clippings.

Comparisons may be made also to leaching studies that used creeping bentgrass. Huang and Petrovic (1994) performed a column lysimeter study of NO_3-N leaching from creeping bentgrass in which average NO_3-N concentration in leachate ranged from 2.2 to 23.1 mg L^{-1}, and the percentage of NO_3-N applied which was lost ranged from 0.9 to 6.6%. At times, the leachate concentration that we observed far exceeded these values as well as the values reported for the percent of applied

NO_3-N lost. The range of application rates of N fertilizer for Huang and Petrovic's (1994) study was similar to ours, however, their N source was $(NH_4)_2SO_4$ and ours was NH_4NO_3 which may have caused differences in the amount of NO_3-N leached.

In Bowman et al.'s (1998) creeping bentgrass column lysimeter study, peak NO_3-N leachate concentration averaged 27 mg L^{-1} for shallow-rooted genotypes and 12 mg L^{-1} for deep-rooted genotypes. An average of 38 and 18% of applied N leached from the shallow and deep-rooted genotypes, respectively. The N rate was 50 kg ha^{-1} approximately half that of our lowest N rate (98 kg N ha^{-1}). This is one likely reason for the lower percentage of applied N lost and lower concentrations of NO_3-N observed in the study.

Mancino and Troll (1990) observed total leaching losses ranging from <0.5% to 4% of applied N depending upon experimental treatment. At the application rate of 49 kg N ha^{-1}, NO_3-N concentration in leachate ranged from 0.14 to 69 mg L^{-1} depending upon N source and the number of days since application. While the range of NO_3-N concentration of leachate observed is quite similar to our observations, the percent of applied N lost is much less. This discrepancy may be explained by the lower application rates of N utilized by Mancino and Troll (1990) but is more likely due to the timing of their irrigation. While Mancino and Troll (1990) applied a total of 38 mm per week of irrigation in three equal applications, our irrigation amounts ranged from 25 to 90 mm per week and were applied in a single, weekly application.

Based upon our findings, as well as the previous work of others, it is clear that the specific conditions under which turfgrass NO_3-N leaching studies are performed generate a wide variety of outcomes. The percent of applied N that we found in leachate (1 to 63%) falls within those values reported in Petrovic's (1990) comprehensive review.

Returning grass clippings to bentgrass turf mowed at golf fairway height increases the NO_3-N concentration and mass loss of NO_3-N in percolating soil water. We observed from 13 to 63% loss of applied N, depending upon N fertilization rate, when clippings were returned. For the most part, flow-weighted NO_3-N concentrations were less than the US Environmental Protection Agency's maximum contaminant level (MCL) of 10 mg L^{-1} unless excessive fertilization (196-392 kg N ha^{-1}), irrigation, or the return of clippings occurred. On average, the N loss observed when clippings were removed was more than doubled when clippings were returned. This loss became greater as N rate and irrigation increased. The results of this study indicate that N rates should be reduced when clippings are returned to fairway bentgrass turf under intensive management to reduce the potential of nutrient pollution to receiving waters.

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