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Nitrogen Fertilizer Form and Associated Nitrate Leaching from Cool-Season Lawn Turf

Karl Guillard* and Kelly L. Kopp

ABSTRACT

Various N fertilizer sources are available for lawn turf. Few field studies, however, have determined the losses of nitrate ($\text{NO}_3\text{-N}$) from lawns receiving different formulations of N fertilizers. The objectives of this study were to determine the differences in $\text{NO}_3\text{-N}$ leaching losses among various N fertilizer sources and to ascertain when losses were most likely to occur. The field experiment was set out in a completely random design on a turf typical of the lawns in southern New England. Treatments consisted of four fertilizer sources with fast- and slow-release N formulations: (i) ammonium nitrate (AN), (ii) polymer-coated sulfur-coated urea (PCSCU), (iii) organic product, and (iv) a nonfertilized control. The experiment was conducted across three years and fertilized to supply a total of $147 \text{ kg N ha}^{-1} \text{ yr}^{-1}$. Percolate was collected with zero-tension lysimeters. Flow-weighted $\text{NO}_3\text{-N}$ concentrations were 4.6, 0.57, 0.31, and 0.18 mg L^{-1} for AN, PCSCU, organic, and the control, respectively. After correcting for control losses, average annual $\text{NO}_3\text{-N}$ leaching losses as a percentage of N applied were 16.8% for AN, 1.7% for PCSCU, and 0.6% for organic. Results indicate that $\text{NO}_3\text{-N}$ leaching losses from lawn turf in southern New England occur primarily during the late fall through the early spring. To reduce the threat of $\text{NO}_3\text{-N}$ leaching losses, lawn turf fertilizers should be formulated with a larger percentage of slow-release N than soluble N.

VARIOUS FORMULATIONS OF N-based fertilizers are available for lawn turf. These products range in formulation from highly soluble, fast-release sources of N such as urea, ammonium nitrate, and ammonium sulfate to low solubility, slow-release sources such as isobutylidene diurea, coated ureas, ureaformaldehyde, or organic-based materials. Previous leaching studies with cool-season turf have used soluble, fast-release N formulations (Gross et al., 1990; Harrison et al., 1993; Miltner et al., 1996; Liu et al., 1997), or a combination of fast- and slow-release N formulations (Starr and DeRoo, 1981; Morton et al., 1988; Gold et al., 1990).

It has been reported that the $\text{NO}_3\text{-N}$ leaching losses from cool-season turf are higher with soluble N formulations than with slow-release formulations (Nelson et al., 1980; Mosdell and Schmidt, 1985; Sheard et al., 1985; Petrovic et al., 1986; Mancino and Troll, 1990; DeNobili et al., 1992; Geron et al., 1993; Engelsjord and Singh, 1997). Other factors in addition to N solubility will affect the leaching potential from turf and these include, but

are not limited to, soil type, irrigation rate, N-application rate, frequency and timing of fertilizer applications, stand density, rooting characteristics, and plant N demands (Petrovic, 1990). Results from cool-season turf leaching studies have varied considerably because of the interactions of these factors with N solubility.

There have been several reported field studies that have directly compared $\text{NO}_3\text{-N}$ leaching from cool-season turf receiving fast- and slow-release N fertilizers (Sheard et al., 1985; Petrovic et al., 1986; DeNobili et al., 1992; Geron et al., 1993; Engelsjord and Singh, 1997). Of these, only the studies of Petrovic et al. (1986) and Geron et al. (1993) were conducted under lawn management conditions; the others were managed under golf or athletic field conditions. The dominant mechanisms for $\text{NO}_3\text{-N}$ loss from cool-season turf seem to be: (i) late seasonal flushes associated with autumn or early-winter rain storms, (ii) excessive irrigation or precipitation exceeding evapotranspiration, and (iii) winter thaws and spring snowmelt (Mosdell and Schmidt, 1985; Morton et al., 1988; Gold et al., 1990; Geron et al., 1993; Liu et al., 1997).

Traditional agricultural crop production in southern New England has declined rapidly during the last 30 yr. As urban and suburban development encroaches into rural landscapes, turf is replacing cropland as the principal managed land cover in the region. This situation is not unique to this region of the country; turf associated with suburban development is replacing cropland along the entire Eastern Seaboard of the United States. Although most turf areas are not regarded as agricultural cropland, they may receive comparable amounts of fertilizers as are applied to cropland.

There are few field studies that report $\text{NO}_3\text{-N}$ leaching losses from cool-season lawn turf fertilized with various N sources. More studies are needed to determine the fate and transport of $\text{NO}_3\text{-N}$ applied to turf in urban or suburban settings. Therefore, this study was conducted to determine the $\text{NO}_3\text{-N}$ concentrations and losses from turfgrass managed as lawn from various forms of N and to determine the season when most of these losses were likely to occur.

MATERIALS AND METHODS

A field experiment was conducted at the University of Connecticut's Plant Science Research and Teaching Farm in Storrs, CT, from 28 Oct. 1996 to 1 Nov. 1999. Weather data were recorded on site with a Campbell Scientific (Logan, UT)

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Abbreviations: AN, ammonium nitrate; MCL, maximum contaminant level; PCSCU, polymer-coated sulfur-coated urea; PET, potential evapotranspiration.

automated weather station. Potential evapotranspiration (PET) was estimated for each day by using a modified Penman–Monteith model (Allen et al., 1998), then summed for each month for data presentation. The soil at the site was a Paxton fine sandy loam (coarse-loamy, mixed, active, mesic Oxyaquic Dystrudept), with sand, silt, and clay content of 574, 303, and 123 g kg⁻¹, respectively, 52 g kg⁻¹ organic matter, and cation exchange capacity of 13 cmol kg⁻¹ in the 0- to 20-cm profile depth. The experiment was set out in a completely random design with two replicates on lawn turf typical of the region. The long-term history of the study site indicated a minimally maintained lawn for at least 10 yr with no fertilizer inputs, then 2 yr before this study, the area was completely renovated and reseeded with a mixture containing Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), and creeping red fescue (*Festuca rubra* L.). This sward was then maintained for higher quality and received 147 to 196 kg N ha⁻¹ yr⁻¹ for the next two years. In the third year following renovation, we started our experiment. Plots were 3.0 × 3.6 m and were mowed as needed to a height of 3.8 cm with clippings returned. No supplemental irrigation was supplied.

Treatments consisted of four N fertilizer sources: (i) AN, ammonium nitrate, 34–0–0 (N–P–K), all soluble N; (ii) PCSCU, polymer-coated sulfur-coated urea (LESCO Elite Poly Plus 21–1.7–9, with 95% of the material polymer coated and containing 20.15% urea N, 15.1% slow-release N, and 0.85% ammoniacal N, a 7-d dissolution rate of 25 to 35%, and a size guide number of 100 to 120; LESCO, Strongsville, OH); (iii) organic (Sustâne 5–0.9–3.3, containing 1.3% ammoniacal N, 0.2% water soluble N, and 3.5% water insoluble N from aerobically composted turkey litter, hydrolyzed feathermeal, and ammonium sulfate; Sustâne/Natural Fertilizer of America, Cannon Falls, MN); and (iv) a nonfertilized control. Fertilizer was applied to supply 49 kg N ha⁻¹ at each application. A total of 147 kg N ha⁻¹ yr⁻¹ was applied for each treatment, except the control in each of three years. Timing and rates of fertilization were consistent with those typical of lawn practices in southern New England. Fertilization dates were: 28 Oct. 1996, 8 May 1997, 23 July 1997, 13 Nov. 1997, 4 June 1998, 16 July 1998, 9 Nov. 1998, 9 May 1999, and 25 June 1999.

Two years before the experiment began, two zero-tension funnel lysimeters (250-mm diameter each, high density polyethylene) were installed at 38-cm depths below nondisturbed soil profiles in the center of each plot. Glass wool was placed into the bottom of each funnel and the native soil excavated for the lysimeters was replaced and packed into the funnels to approximate bulk density of undisturbed soil before they were placed under the plots. High-density polyethylene tubing was attached to the funnels and a T fitting connected the two, producing a single outflow to individual collection wells for each plot. The collection wells were made of 10-cm-diameter polyvinyl chloride pipes that were capped and placed vertically into the soil near the plots. The height of each well was approximately 1 m, and they were positioned below the soil surface to ensure a large reservoir capacity below the T-fitting outlet. A curtain drain was installed upslope of the plots to prevent lateral movement of soil water into the plot area. This consisted of a narrow trench, 15 cm wide and 60 cm deep, with a gravel-covered perforated drainpipe at the bottom of the trench that drained to an outlet approximately 50 m downslope of the plots.

Percolate was collected from the lysimeter wells on a weekly basis, or more often as needed, by using a peristaltic pump, and the volume was recorded. A subsample was placed into HDPE bottles and stored at 4°C or less and analyzed within 28 d for concentrations of NO₃-N plus NO₂-N by using a Cd-reduction method on a Scientific Instruments Continuous

Flow Analysis System (Westco, Danbury, CT). When concentrations were below the detection limit of 0.05 mg L⁻¹, a value of half the detection limit was substituted to permit certain statistical analyses. This was a suitable approach for the AN treatment since the number of nondetects was <15% (USEPA, 1998). The other treatments, however, had 30 to 54% of the water samples with nondetectable concentrations of NO₃-N. To determine if the substitution method was suitable for these samples, unbiased restricted maximum likelihood estimators (RMLE) for censored data were calculated for the means and standard deviations using the methods described in Gibbons and Coleman (2001). The RMLE means and standard deviations were then compared with treatment means and standard deviations computed from the substitution method. Means (mg L⁻¹) for the substitution and RMLE methods were 0.602 and 0.698 for PCSCU, 0.416 and 0.558 for organic, and 0.204 and 0.002 for the control treatments, respectively. Standard deviations for the substitution and RMLE methods were 1.069 and 1.253 for PCSCU, 1.159 and 1.425 for organic, and 0.447 and 0.708 for the control treatments, respectively. Generally, both methods gave similar results, with the exception of the control mean and standard deviation. In this case, the substitution method may have slightly overestimated the control true mean and underestimated the variability. However, since both mean estimates for the control treatment were far below drinking water standards (10 mg NO₃-N L⁻¹) and not at concentrations that may pose environmental threats (≥0.30 mg NO₃-N L⁻¹ when phosphorus is present; Brooks et al., 1991), the substitution method was retained and applied to all data to calculate mass loss and to provide values for analysis of variance. The mass of NO₃-N leached was calculated as the concentration of NO₃-N multiplied by the collection volume. Flow-weighted NO₃-N concentrations were calculated as the total mass of NO₃-N leached divided by the total volume of percolate collected across the three years.

Statistical analyses of the data were conducted using various procedures of SAS (SAS Institute, 1999). Tests of independence were conducted between N source and NO₃-N concentration frequency data by using a log-likelihood ratio χ^2 test within the FREQ procedure of SAS. Differences in NO₃-N concentrations between treatments were determined by using a rank transformation approximation (Helsel and Hirsch, 1995) of data for all individual lysimeter observations combined across the three years. Analysis of variance was performed on the ranked concentration data (the mean rank approximates the median), flow-weighted concentrations, mean yearly mass loss, and mean yearly percentage loss by using the SAS procedure ANOVA. When treatment *F* tests were significant ($p \leq 0.05$), Duncan's new multiple range test ($\alpha = 0.05$) was used to separate means. Correlation analysis between monthly cumulative PET and monthly cumulative NO₃-N leaching losses for each treatment was conducted with the CORR procedure of SAS using the Spearman rank correlation option.

RESULTS

Monthly and annual temperature and precipitation amounts with 30-yr normals (1971–2000) are presented in Table 1. At the beginning of the study in late 1996, precipitation was above normal. Most of 1997 had below normal precipitation on a monthly basis. Total yearly precipitation in 1998 and 1999 was closer to normal precipitation amounts, but monthly totals were highly variable. During the experimental period, temperatures

Table 1. Monthly maximum and minimum temperatures, precipitation totals, and 30-yr normals (1971–2000) for N source leaching study at Storrs, CT, from 1996–1999.

Month	Maximum temperature					Minimum temperature					Precipitation				
	1996	1997	1998	1999	30-yr normal	1996	1997	1998	1999	30-yr normal	1996	1997	1998	1999	30-yr normal
	°C										mm				
January	1.3	1.9	3.9	2.9	0.9	-8.4	-8.1	-3.5	-7.4	-8.2	189	97	129	222	117
February	2.5	5.4	6.0	4.4	2.2	-7.1	-3.9	-2.1	-5.0	-7.1	58	52	88	101	93
March	5.6	6.1	8.0	6.8	7.1	-3.7	-2.5	-1.6	-2.3	-2.3	74	86	201	175	113
April	12.6	12.2	15.6	14.4	13.2	3.5	2.2	3.9	3.7	2.8	180	124	108	34	111
May	19.1	16.8	22.6	19.3	19.6	8.4	6.9	9.8	8.6	8.2	80	76	138	101	102
June	24.0	24.4	21.7	26.3	23.9	14.9	13.5	13.3	14.4	13.0	65	40	188	3	100
July	25.2	26.6	26.1	28.2	26.4	17.1	16.3	16.6	17.5	16.1	186	64	83	149	112
August	24.9	24.6	26.6	15.8	25.5	16.3	15.1	16.4	7.4	15.2	57	121	65	45	108
September	21.9	21.6	23.1	22.9	21.5	13.9	11.6	12.6	13.4	10.9	154	28	73	212	112
October	15.6	14.9	16.0	15.5	15.8	5.9	4.4	6.0	4.4	5.1	165	48	123	124	118
November	7.1	7.2	9.7	12.6	9.7	-0.9	0.1	1.0	2.7	0.7	128	178	61	81	116
December	5.3	3.8	7.4	4.3	3.6	-1.4	-3.3	-1.6	-3.8	-4.9	206	94	39	68	110
Mean or sum	13.8	13.8	15.7	15.0	14.1	4.9	4.4	6.1	4.9	4.1	1543	1008	1295	1315	1312

tended to be slightly higher than normal, particularly during the winter months (November–February).

Nitrate Nitrogen Concentrations

Concentrations of NO₃-N were more likely to be above the detection limit and above the maximum contaminant level (MCL) in percolate from the AN fertilizer compared with the PCSCU, organic, or control treatments (Table 2). Analysis of ranked data across three years indicated that the mean rank (approximation of the median) of NO₃-N concentration in the percolate collected from the AN fertilizer treatment was significantly greater (*p* < 0.0001) than mean rank NO₃-N concentrations from the PCSCU, organic, or control treatments (Fig. 1). Similarly, flow-weighted NO₃-N concentrations across three years from the AN fertilizer treatment were significantly greater (*p* < 0.05) than the 3-yr, flow-weighted NO₃-N concentrations from the PCSCU, organic, or control treatments (Table 3).

Nitrate Nitrogen Mass Loss

Total percolate flow was not different (*p* > 0.05) among treatments. Yearly mean percolation, as a per-

Table 2. Log-likelihood ratio χ^2 tests of independence for detection of NO₃-N in the percolate (≥ 0.05 mg L⁻¹) and for percolate NO₃-N concentration frequencies above the maximum contaminant level (MCL) for drinking water (10 mg L⁻¹) for the N source leaching study at Storrs, CT.

Treatment†	n	Detection frequency	
		<0.05 mg L ⁻¹	≥ 0.05 mg L ⁻¹
AN	71	7	64
PCSCU	73	22	51
Organic	72	26	46
Control	73	39	34
χ^2		34.47	
<i>p</i> > χ^2		<0.0001	
Treatment†	n	MCL frequency	
		<10 mg L ⁻¹	≥ 10 mg L ⁻¹
AN	71	60	11
PCSCU	73	73	0
Organic	72	72	0
Control	73	73	0
χ^2		32.26	
<i>p</i> > χ^2		<0.0001	

† AN, ammonium nitrate; PCSCU, polymer-coated sulfur-coated urea.

centage of yearly mean precipitation covering the experimental period, was 29.4% for AN, 31.2% for PCSCU, 34.9% for organic, and 33.3% for control treatments. These amounts are consistent with expected percolation values for this soil. Percolate flow occurred with seasonal regularity. Few percolate samples were collected from May through September (on only five dates), and most samples were collected from October through March (Fig. 2). Yearly NO₃-N mass leaching losses for the AN fertilizer treatment were significantly greater (*p* < 0.05) than losses of NO₃-N from the PCSCU, organic, or control treatments (Table 3). After correcting for the control, yearly mass leaching losses of NO₃-N

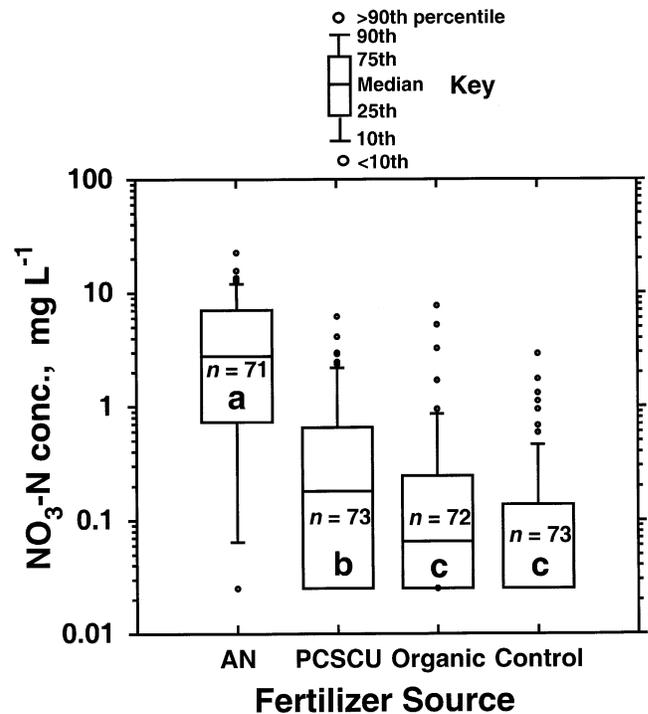


Fig. 1. Box-and-whisker plots of non-flow weighted NO₃-N concentrations in the percolate from cool-season turf plots fertilized with ammonium nitrate (AN), polymer-coated sulfur-coated urea (PCSCU), an organic source, and a nonfertilized control treatment. Boxes with the same letters indicate that the mean ranks are not significantly different according to Duncan's new multiple range test (α = 0.05).

Table 3. Percolate flow-weighted NO₃-N concentrations (FWC), mean yearly NO₃-N mass leaching losses, and percentage losses of N based on amount applied after correcting for losses from the nonfertilized control plots for the N source leaching study at Storrs, CT.

Treatment†	FWC	Mean yearly mass loss	Loss per year
	mg L ⁻¹	kg ha ⁻¹ yr ⁻¹	%
AN	4.6 a‡	25.8 a	16.8 a
PCSCU	0.57 b	3.7 b	1.7 b
Organic	0.31 b	2.0 b	0.6 b
Control	0.18 b	1.1 b	*
F test	*	*	*

* Significant at the 0.05 probability level.

† AN, ammonium nitrate; PCSCU, polymer-coated sulfur-coated urea.

‡ Values within a column followed by the same letters are not significantly different ($p < 0.05$) based on Duncan's new multiple range test ($\alpha = 0.05$).

as a percentage of N applied (147 kg N ha⁻¹ yr⁻¹) were significantly greater ($p < 0.05$) for the AN fertilizer treatment compared with the PCSCU and organic fertilizer treatments (Table 3). Leaching losses of NO₃-N were negatively correlated with monthly cumulative PET (Fig. 3). Once monthly cumulative PET reached 30 mm or more, the probability of NO₃-N leaching was low.

DISCUSSION

The loss of NO₃-N in our study was affected both by N source and by season. The results are similar to several previously reported cool-season turf studies that have shown more NO₃-N leaching losses from soluble N forms than from less soluble N forms (Nelson et al., 1980; Mosdell and Schmidt, 1985; Sheard et al., 1985; Petrovic et al., 1986; Mancino and Troll, 1990; DeNobili et al., 1992; Geron et al., 1993; Engelsjord and Singh, 1997). The NO₃-N leaching losses from PCSCU and organic treatments in our study suggest that lower solubility N fertilizers will present a much lower risk of water pollution from lawns, and will not be substantially different from losses originating from nonfertilized turf

areas. Concentrations and losses of NO₃-N from the nonfertilized control treatment and the low-soluble N sources used in our study were similar to background levels (≤ 0.20 mg NO₃-N L⁻¹) observed from percolate collected from forested landscapes in our region (Gold et al., 1990). This reinforces the recommendation that lower-solubility N sources should be used in environmentally sensitive areas or where there are pollution concerns with turf fertilization.

Percolate flow and associated NO₃-N leaching losses were primarily observed when monthly cumulative PET was < 30 mm with normal or above normal rainfall periods, and following snow melt (Fig. 2 and 3). When monthly cumulative PET was > 30 mm or when precipitation was below normal, few leaching events occurred. For example, in 1997 no percolate was collected during the growing season and throughout December, which was probably attributable to below-normal precipitation. Percolate flow resumed in January 1998, which had above normal temperatures and precipitation (Table 1). Our results indicate the importance of continuous sampling in turf leaching studies during all seasons. It is often presumed that once the winter season begins, the ground becomes frozen and no leaching occurs. Our data show that percolate was frequently captured during the winter and early spring months, and contributed to a significant portion of the NO₃-N losses under our conditions. The deep collection reservoirs also prevented the percolate sample from freezing during the winter before removal of the sample.

Seasonal effects on NO₃-N leaching from turf have been reported in a few previous studies. Gold et al. (1990) reported that greatest NO₃-N concentrations and leaching losses from lawn turf in Rhode Island occurred during spring snow melt. Geron et al. (1993) also observed that NO₃-N leaching losses from newly established turf in Ohio were more a function of seasonal and climatic variations (more during the winter vs. late

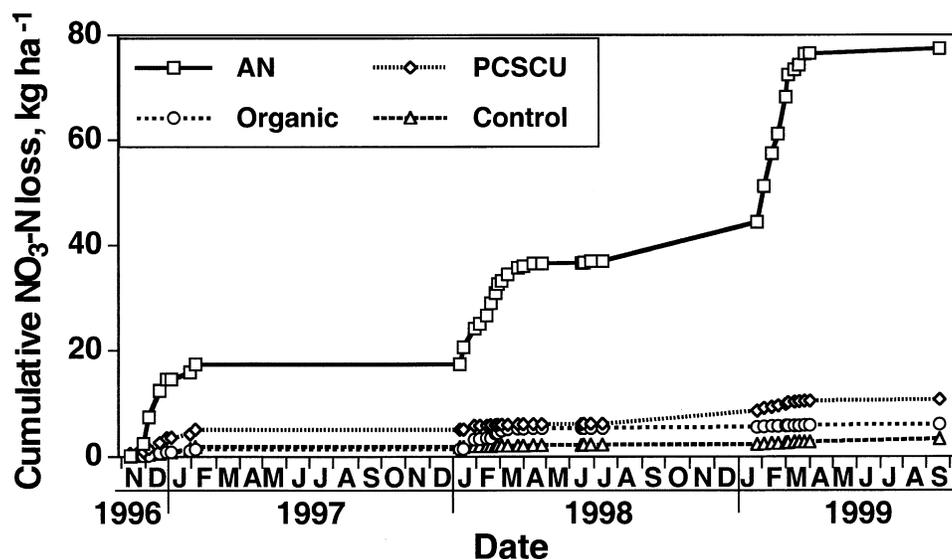


Fig. 2. Cumulative mass NO₃-N leaching losses in the percolate from cool-season turf plots fertilized with ammonium nitrate (AN), polymer-coated sulfur-coated urea (PCSCU), an organic source, or a nonfertilized control treatment.

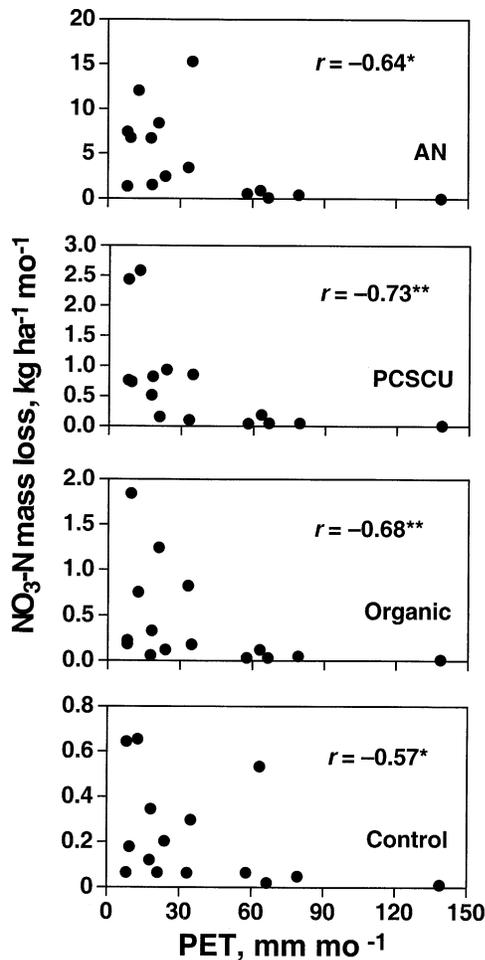


Fig. 3. Relationship between monthly cumulative potential evapotranspiration (PET) and monthly cumulative NO₃-N leaching losses for different N fertilizer treatments applied to lawn turf (AN, ammonium nitrate; PCSCU, polymer-coated sulfur-coated urea). Significance of Spearman rank correlation coefficient (r) is indicated at * ($p < 0.05$) and ** ($p < 0.01$).

spring and summer) than timing or form of applied fertilizer N. Episodic NO₃-N leaching losses will occur during the growing season provided that sufficient precipitation is received. In our case, above normal precipitation during April, May, and June 1998 resulted in isolated percolate collections during the early- to mid-summer period (Fig. 2). This was unusual and occurred only during 1998. Higher PET rates during our mid-summer period normally prevent soil moisture from reaching a content that is sufficient to induce leaching, as shown in Fig. 3. Morton et al. (1988) indicated that in situations where high antecedent soil water conditions exist, such as in frequently and heavily irrigated turf, natural rainfall added to the precipitation received from irrigation can result in significant episodic NO₃-N leaching losses. In their study, NO₃-N concentrations approached or exceeded 10 mg L⁻¹ under these conditions. This stresses the importance of maintaining adequate, but not excessive soil moisture for turf needs.

In our study, NO₃-N concentration in the percolate from the AN treatment was greater than the MCL standard for drinking water in about 15% of the samples;

flow-weighted NO₃-N concentration across the three years was less than half the MCL. Although lower than the MCL for drinking water, the flow-weighted NO₃-N concentrations from the soluble AN treatment recorded in our study could be a factor in the degradation of bay and estuarine water quality (Ryther and Dunstan, 1971). In the presence of P, NO₃-N concentrations as low as 0.3 mg L⁻¹ can prompt the development of algal blooms (Brooks et al., 1991). Nitrogen has been identified as the primary pollutant contributing to hypoxia in Long Island Sound (New York Department of Environmental Conservation–Connecticut Department of Environmental Protection, 2000), which is the largest waterbody of economical and ecological importance in our area. In coastal environments such as ours, relatively small leaching losses of NO₃-N from fertilized lawns may be ecologically significant by contributing to the overall N loading of the receiving waters. Whereas in other inland regions or environments where yearly precipitation is lower and winter recharge of ground water is not as great, these losses may be of less concern relative to other land uses that generate potentially greater nitrate leaching losses.

The majority of NO₃-N leaching events occurred from late fall to early spring in our study. Therefore, implementing a turf fertilizer program that does not result in the buildup of excess soil NO₃-N going into the late fall period seems prudent. A similar conclusion was reached with studies conducted in the Pacific Northwest by Miltner et al. (2001). Their data show a rapid increase of inorganic N in the soil during the late fall that was attributed to mineralization and nitrification. Plant uptake of N (as measured by clipping N concentration), however, could not keep pace with mineralization and nitrification. The result was a buildup of soil NO₃-N that increased the potential for leaching, especially when fertilizer N was applied.

Our N rates were based on a typically recommended practice in our area of 147 kg N ha⁻¹ split into three separate applications of 49 kg N ha⁻¹. This rate may have been more than was needed to sustain acceptable quality at this site, because clippings were also returned. Kopp and Guillard (2002) found that the quality of the lawn turf at the same location used in this study was equivalent between a 98 kg N ha⁻¹ rate with clippings returned and a 196 kg N ha⁻¹ rate with clippings removed. The N provided by the clippings afforded the opportunity to reduce fertilizer N rates without a loss in quality. This has been reported also in another Northeast study (Heckman et al., 2000).

The agronomic benefits of late-season N fertilization of turf have been reported (Hanson and Juska, 1961; Powell et al., 1967; Wilkinson and Duff, 1972; Wehner et al., 1988; Wehner and Haley, 1993). Little is known, however, about the fate of N after late-season application and the effects on water quality. Popular perception, even among turfgrass scientists, is that late-season fertilization of lawns poses little or no threat to the environment because it stimulates rooting and rhizome activity, which is sufficient to capture the applied N. In a review on the fate of N applied to turfgrass, however, Petrovic (1990) raised caution concerning this practice

from an environmental risk perspective, especially with soluble fertilizer formulations. Liu et al. (1997) reported that cool-season turfgrass species and cultivars grown in Rhode Island differed substantially in their N-use efficiencies, and they indicated that fall or winter fertilizer application might further enhance the leaching potential of some grasses that inherently express poor N-use efficiency.

These observations in addition to our data suggest that late-season fertilization of turf with certain soluble N formulations (particularly those containing NO_3) may increase the potential of N losses by leaching in our climate. This observation of greater leaching losses during the late fall through early spring seasons may also hold true in other coastal climates where there is greater potential for winter ground water recharge than for inland climates. Timing of N application to Kentucky bluegrass turf after establishment did not affect NO_3 -N leaching losses in Ohio (Geron et al., 1993) or in Michigan (Miltner et al., 1996). This is contrary to what we observed, and may be attributed to the differences in the amounts of nonfrozen precipitation received during the late fall–early winter periods between the southern New England coastal climate (more rain) and the inland continental Ohio and Michigan climate (more snow).

CONCLUSIONS

This study suggests that NO_3 -N leaching from cool-season lawn turf is more likely during the late fall through the early spring in southern New England than during late spring through summer. Consequently, soil NO_3 -N concentrations in our climate should be minimized before this leaching period to reduce the potential for leaching losses. To further reduce the threats of NO_3 -N leaching in coastal environments of southern New England, lawn turf fertilizers should be formulated with a larger percentage of slow-release N than with soluble N.

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