Influence of Overwatering and Fertilization on Nitrogen Losses from Home Lawns

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ABSTRACT

Fertilized home lawns represent a potential source of NO_3-N contamination to groundwater and surface waters. The waterborne losses of inorganic N from Kentucky bluegrass (*Poa pratensis* L.) turf subjected to three levels of N fertilization (0, 97, and 244 kg N ha^{-1} yr^{-1} as urea and methylene urea) and two irrigation regimes (scheduled by tensiometer and overwatering with 3.75 cm of water per week in addition to rainfall) were measured. The site was located on a Merrimac sandy loam (sandy, mixed, mesic Typic Dystrochrept). Soil-water percolate was collected by suction plate lysimeters placed below the root zone. Surface runoff was quantified with orifice flow splitters. Soil-water percolate flux comprised >93% of the total water and inorganic-N discharged from all treatments. Mean annual flow weighted concentrations of inorganic N in soil-water percolate were below the U.S. drinking water standard on all treatments and ranged from 0.36 mg L^{-1} on the overwatered, unfertilized, control treatment to 4.02 mg L^{-1} on the overwatered, high N treatment. Annual losses ranged from 32 kg ha^{-1} on the overwatered high N rate treatment to 2 kg ha^{-1} on the scheduled irrigation, unfertilized, control treatment. Overwatering in conjunction with fertilization generated significantly higher annual flow weighted concentrations and mass loss than the unfertilized controls. Nitrogen loss and concentrations from the scheduled irrigation treatments were not significantly different from the controls.

Additional Index Words: Nitrate-nitrogen, Turfgrass, Groundwater pollution, Water quality, Irrigation scheduling.

Since 1970, pesticide and fertilizer use on home lawns has steadily increased (Watschke, 1983). The growth of chemical use suggests the possibility for an increase in off-site losses and subsequent environmental contamination. Lawn care chemicals may be applied in close proximity to impervious zones with high potential for surface runoff. Miller et al. (1974), in their study of groundwater contamination in the northeastern USA, stressed the need for long-term studies to determine if home lawn agrichemicals have penetrated the soil zone and entered the groundwater system.

Several researchers have described conditions under which they found substantial NO_3-N leaching from fertilized cool season turfgrass (Owen and Barraclough, 1983; Rieke and Ellis, 1974). Nitrate-N is a drinking water contaminant with a U.S. drinking water standard of 10 mg L^{-1} (USEPA, 1976). Leaching of NO_3 is of particular

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concern on Long Island, NY, and the southern New England states where permeable, outwash soils overlie unconfined drinking water aquifers. Coastal estuaries and bays have been found to be N limited, and may be degraded by concentrations of NO_3-N much less than the drinking water standard of 10 mg L^{-1} (Ryther and Dunstan, 1971). Other researchers have shown little increase in NO_3-N leaching from fertilized turfgrass (Starr and DeRoo, 1981; Snyder et al., 1984). Starr and DeRoo (1981) monitored the fate of N applied to cool season turfgrasses in southern New England and found low concentrations of NO_3-N in leachate when moderate rates of N were applied and no supplemental irrigation water was used.

Irrigation has been shown to significantly increase NO_3-N leaching (Snyder et al., 1984; Endelman et al., 1974; Timmons and Dylla, 1981; Rieke and Ellis, 1974). Home lawns are typically watered with little regard for soil moisture status or the water holding capacity of the soil. Where irrigation is automatically controlled, rates are often selected to meet maximum evaporative demands, resulting in routine overwatering (Snyder et al., 1984). Excessive watering will increase antecedent soil moisture, thereby promoting additional leaching and surface water runoff from natural storm events or from the supplemental water alone.

The goal of this study was to quantify N losses from turf subjected to the range of fertilization and watering practices generally used on home lawns. Commercial applicators often employ several practices that past studies have shown to minimize off-site transport of N (Rieke and Ellis, 1974; Brown et al., 1982). Nitrogen is frequently applied in the form of urea in combination with some form of slow release materials, rather than in immediately available forms. The fertilizer is usually applied in small increments throughout the growing season, which is thought to minimize high N concentrations in the root zone.

However, commercial home lawn care companies often apply greater annual amounts of N than individual homeowners. A survey of 460 households on Long Island found that homeowners applied an average of 122 kg N ha^{-1} yr^{-1} to their lawns (Koppelman, 1978). Many commercial operations apply 220 to 293 kg N ha^{-1} yr^{-1} (J.F. Wilkinson, Old Fox Lawn Care, Inc., 1985, personal communication). The objective of this study was to determine the effects of varying N fertilization rates and irrigation regimes on waterborne losses of inorganic N from home lawns.

MATERIALS AND METHODS

Site Description

Hydrologically isolated plots were established at the Univ. of Rhode Island, Kingston, to monitor surface and subsurface water loss from turfgrass. The soil at the site was classified as a Merrimac sandy loam. Twelve plots (2.1 by 15.2 m) were instrumented for monitoring overland flow. Eighteen plots were instrumented for subsurface collection. Runoff plots had 2 to 3% slope toward surface collection units and no cross slope. Monitoring occurred from October 1984 through October 1986. Soil-water percolate from six treatments, consisting of three rates of N, coupled with two irrigation regimes, was evaluated. Overland runoff was evaluated for two rates of N and two irrigation regimes. Three replications of each combination of irrigation and fertilizer treatment were established in a completely randomized design.

A mixture of 90% Kentucky bluegrass and 10% red fescue (*Festuca rubra* L.) was planted during the fall of 1980. The turfgrass was maintained at a 5.0- to 7.5-cm height and the clippings remained on the plots.

Instrumentation

A subsurface sprinkler head system was used to irrigate the study site. Half and quarter circle, flat spray nozzles were employed to ensure controlled applications. In addition, plots receiving different irrigation rates were separated by 1.5-m sod buffer strips. Application rate was 5.0 cm h^{-1}. Uniformity of application was measured at >90%.

Ceramic lysimeter plates obtained from Soil Moisture, Inc. (Santa Barbara, CA) were used to measure the flux and quality of soil-water percolate. Each lysimeter was 27 cm in diameter with a 0.05-MPa air entry value. Soil-water percolate samples were collected and temporarily stored in a polyvinyl chloride (PVC) vacuum reservoir stand pipe inserted to a depth of 70 cm. Prior to installation the plates and PVC collection reservoirs were cleaned as described by Miller (1977).

The soil moisture plates were placed 20 cm below the thatch layer where the sandy loam solum abruptly changed to a coarse gravelly sand deposited as glacial outwash. The depth of root penetration was observed to extend to 15 cm. Concentrations of inorganic N that reached 20 cm were assumed to approximate concentrations that would travel to the groundwater. Tensiometers located in the study area revealed that a potential of −0.01 MPa corresponded to the field capacity of this soil 48 h after saturation. To simulate undisturbed drainage, the plates were maintained at a suction of −0.01 MPa after any event intense enough to produce drainage.

Following any precipitation or irrigation event that generated surface runoff or soil-water percolate, samples were removed from the collection system at 24-h intervals for flow quantification and chemical analysis. Any samples not analyzed immediately were frozen at −10 °C. Samples were analyzed for NH_4-N by the steam distillation method and then reduced with DaVarda's alloy and analyzed for NO_2-N and NO_3-N (Bremner, 1965). To ensure quality control, standards of NH_4 and NO_3 were routinely analyzed.

Surface water flow was collected by means of an orifice flow splitter (McLeod and Hegg, 1984) produced by the Engineering Instrument Shop at the Univ. of Rhode Island. Flow splitters were individually calibrated. They directed 9.6 to 11.3% of the total flow to 230-L collection barrels. Runoff water samples were analyzed in the same fashion as the soil-water percolate.

Fertilizer Application

Chemical applications began in June 1984, 4 months before monitoring was initiated. The N application rates investigated were 0, 97, and 244 kg N ha^{-1} yr^{-1} for the control, low, and high N treatments, respectively. Nitrogen was applied at a rate of 48.5 kg ha^{-1} in June and September to the low and high N treatment. The high N treatments received additional applications in July and August (24 kg ha^{-1} per application) and in November (97 kg ha^{-1}) to simulate the commercial home lawn care application rates. Nitrogen was applied in a liquid form as 50% urea and 50% Fluf® (flowable liquid ureaform, manufactured by W.A. Cleary, Somerset, NJ). The low N treatments received 17 kg P ha^{-1} yr^{-1} and 17 kg K ha^{-1} yr^{-1}, whereas the high N treatments had applications of 42 kg P ha^{-1} yr^{-1} and 42 kg K ha^{-1} yr^{-1}.

Irrigation Schedules

Plots were irrigated at two rates. These rates were (i) a scheduled rate to avoid drought stress and to prevent percolation from the root zone, and (ii) a rate to simulate overwatering. On scheduled irrigation plots, irrigation was initiated when the soil-water potential measured by two out of three tensiometers attained −0.05-MPa tension. To wet the soil to field capacity (−0.01 MPa) while preventing drainage from the root zone, 1.2 cm of water was applied. This irrigation depth was based on a soil moisture characteristic curve obtained in the laboratory from undisturbed soil cores of the Ap horizon (Richards, 1965). The rate chosen to simulate overwatering was three applications per week of 1.25 cm per application (3.75 cm wk^{-1}), regardless of rainfall. This irrigation depth represents the mean maximum weekly evapotranspiration in Rhode Island during the summer months (NOAA, 1982).

Soil-water Percolate Flux

For most of the rainfall and irrigation events, the plates collected all the expected percolate. However, on large storm events the plates were unable to adequately quantify percolate flux (volume plate per area per event). During the study, several storms ≥8.0 cm d^{-1} generated no overland runoff from irrigated turfgrass, while the lysimeters collected approximately 2.5 cm of percolate. Since soil storage above the collection plates could not account for the additional water, a mass balance model was created to correct the percolate estimates from large storm events. Hergert (1986) also used suction lysimeters to quantify flux volume. He found similar discrepencies during large flux events and used a water balance to improve flux estimates.

Daily percolation (P_i) was computed by the equation of Kincaid et al. (1979)

$$P_i = PPT_i - ET_i + SM_{i-1} - SM_i$$

where P_i = water percolating from root zone on a given day (cm), PPT_i = precipitation or irrigation on a given day (cm), ET_i = evapotranspiration on a given day derived from the modified Penman equation (cm), SM_{i-1} = soil moisture content on the previous day (cm), and SM_i = soil moisture content on a given day (cm).

Following the approach of Smith and Williams (1980), leaching was assumed to occur whenever the soil moisture of the root zone exceeded field capacity. All of the precipitation was assumed to infiltrate into the soil. Potential evapotranspiration was computed using the modified Penman equation (Doorenbos and Pruitt, 1977). Meterological data was obtained from the Rhode Island Agric. Exp. Stn. weather station located 1200 m from the study site.

The predictive mass balance model was run for the entire study period. On events where the observed percolation differed by 1.0 cm or more from the predicted percolate flux, the corrected percolate flux value was used and chemical losses calculated from that value. For all other events, the observed flux was used in calculation of N loss.

Statistical Analysis

Data were subjected to analysis of variance procedures using the Statistical Analysis System (SAS Inst., Inc., 1982). Significant differences in means were tested using the least significant difference test at the 0.05 level. Beginning in the winter of 1986, rodent activity was observed in the turfgrass directly over one of the lysimeters on the high N, scheduled irrigation treatments. A corresponding increase in inorganic-N concentrations from this lysimeter was observed. Inorganic-N concentrations rose in excess of 40 mg L^{-1} for the remainder of the study, while the other replicates of this treatment averaged <3 mg L^{-1}. Results from this replication were excluded from the data set during the second year of study.

RESULTS AND DISCUSSION

Soil-water Percolation

An annual and seasonal hydrologic balance for the periods studied is presented in Table 1. Since there were no significant differences in the observed quantity of soil-water percolate between N treatments, the observed and corrected flux estimates were averaged over the N treatments. Water losses estimated from the sum of evapotranspiration and percolation estimates derived solely from the plate lysimeters did not account for 13 to 56% of the total water inputs. Correcting the lysimeter flux for storms where the observed percolation differed by 1.0 cm or more (large storms) from the flux predicted by the hydrologic model markedly improved the mass water balance. The discrepency between seasonal inputs and losses dropped to a range of 5 to 33% with the corrected estimates of percolation. The percolation estimates corrected for large storms were used in computing mass N loss estimates and seasonal flow weighted N concentrations.

Table 1. Annual and seasonal hydrologic balance for irrigated and nonirrigated treatments.

Components of hydrologic balance	Nonirrigation period Oct. 1984–June 1985		Irrigation period July–Oct. 1985		Nonirrigation period Oct. 1985–June 1986		Irrigation period June–Oct. 1986		Mean annual values	
	Schd.†	Over.‡	Schd.	Over.	Schd.	Over.	Schd.	Over.	Schd.	Over.
	cm									
Inputs										
Precipitation	63.6	63.6	50.3	50.3	71.6	71.6	37.5	37.5	111.5	111.5
Irrigation	0.0	0.0	2.5	50.8	0.0	0.0	0.0	64.8	1.3	57.8
Total	63.6	63.6	52.8	101.1	71.6	71.6	37.5	102.3	112.8	169.3
Losses										
ET	28.9	28.9	18.3	27.1	26.2	26.2	26.6	36.0	50.0	59.1
Percolation	26.2	25.7	26.8	68.4	21.8	22.0	9.2	44.9	42.0	80.5
	(3.8)§	(3.0)	(2.4)	(4.0)	(6.9)	(5.9)	(3.3)	(7.2)		
Runoff	2.0	2.0	0.2	0.2	0.0	0.0	0.0	0.0	1.1	1.1
Total loss	57.1	56.6	45.3	95.7	48.0	48.2	35.8	80.9	93.1	140.7
% Unaccounted	10.2	11.0	14.2	5.3	33.0	32.7	4.5	20.9	17.5	16.9

† Sched. = scheduled irrigation treatments. ‡ Over. = overwatered treatments. § ( ) = standard deviation of nine plots.

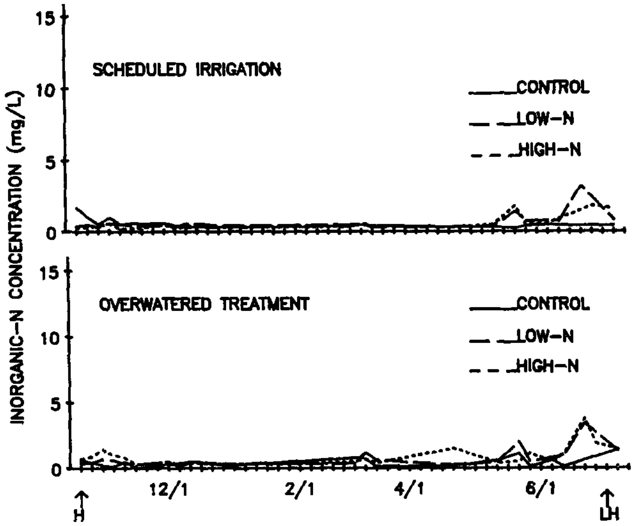

Fig. 1. Inorganic-N concentrations by event, 1 Oct. 1984 to 30 June 1985. ↑ = fertilization date; H = fertilizer application to high N treatment; and L = fertilizer application to low N treatment.

Corrected soil-water percolation averaged 42 cm yr^{-1} on the scheduled irrigation treatments compared to 81 cm yr^{-1} on the overwatered treatments (Table 1). Approximately 63% of the soil-water percolate from the root zone occurred during the nonirrigated periods (October–June) on the scheduled treatments vs. 29% for the overwatered treatments. During the two irrigation periods studied, soil-water percolate from the overwatered treatments was approximately three times that generated by the scheduled irrigation plots.

The potential for off-site chemical losses depends on both the frequency and quantity of percolation from the root zone. On the overwatered treatments an average of 45 events per summer generated percolate below the root zone. In contrast, percolation events from the scheduled treatments averaged nine per summer.

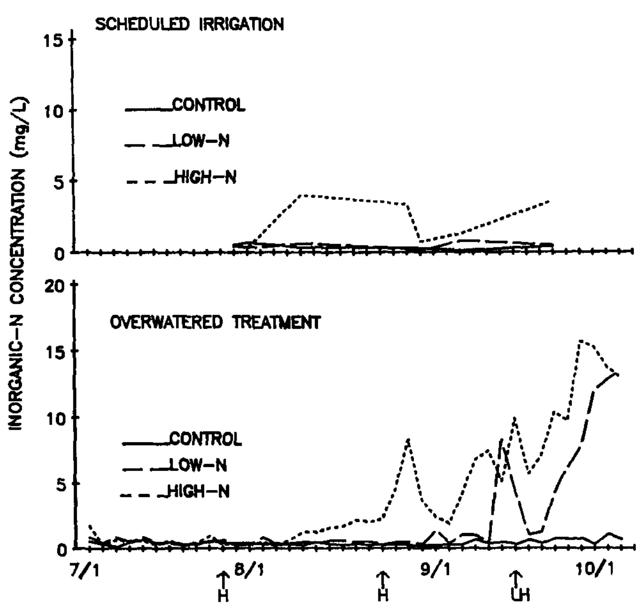

Fig. 2. Inorganic-N concentrations by event, 1 July to 8 Oct. 1985. ↑ = fertilization date; H = fertilizer application to high N treatment; and L = fertilizer application to low N treatment.

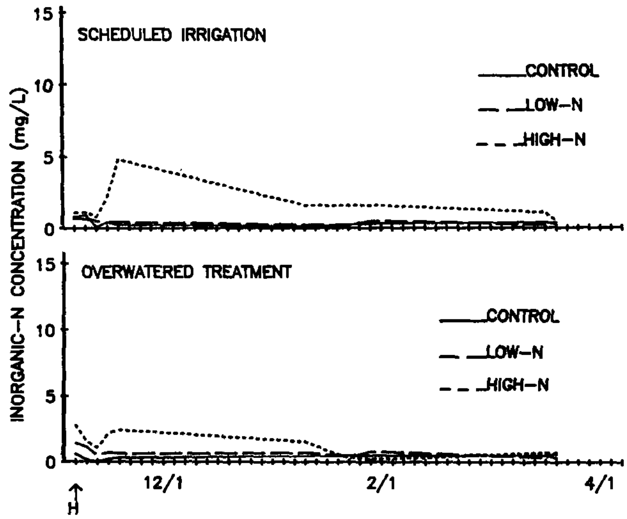

Fig. 3. Inorganic-N concentrations by event, 9 Oct. 1985 to 1 June 1986. ↑ = fertilization date; H = fertilizer application to high N treatment; and L = fertilizer application to low N treatment.

Soil-water N Concentrations

The safest approach to assess the potential for NO_3 contamination of groundwater from samples of soil-water percolate is to assume that all forms of inorganic N that leached from the root zone would eventually convert to NO_3-N. Nitrate-N comprised 77% of the total inorganic N in leachate from all plots during the study. Mean NH_4-N concentrations were <0.52 mg L^{-1} on all

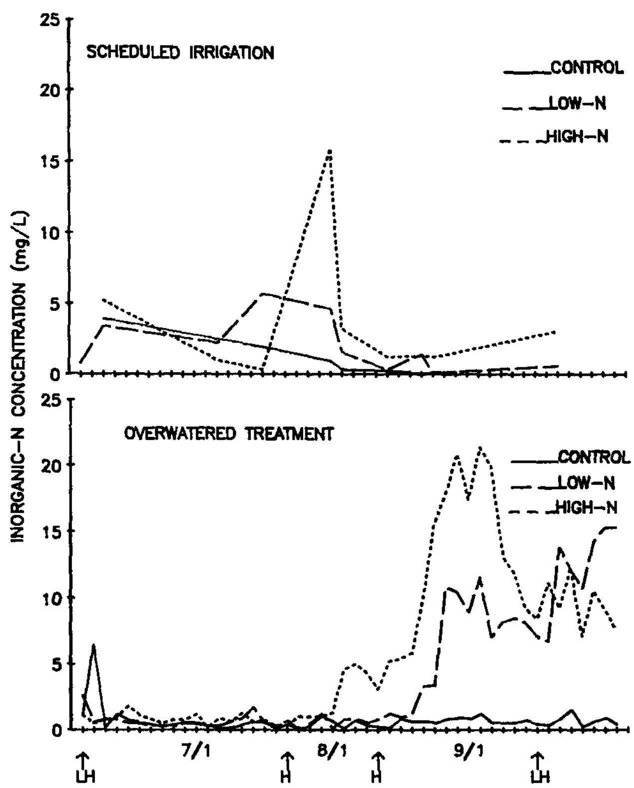

Fig. 4. Inorganic-N concentrations by event, 2 June to 1 Oct. 1986. ↑ = fertilization date; H = fertilizer application to high N treatment; and L = fertilizer application to low N treatment.

treatments (data not shown). The following results and discussion will not differentiate between inorganic-N fractions.

Mean inorganic-N concentrations for each event that generated percolate below the root zone are depicted in Fig. 1 to 4. The control treatments maintained percolate concentrations <2 mg L^{-1} during all events. The only percolation events from the controls with concentrations in excess of 1 mg L^{-1} occurred in late spring.

Although the high N treatments received 97 kg N ha^{-1} each fall, the percolate concentrations of inorganic N never exceeded 5 mg L^{-1} (one-half of the drinking water standard of 10 mg L^{-1}) throughout the succeeding fall, winter, or spring (Fig. 1 and 3). Dramatic increases in percolate concentrations of inorganic N were observed in late summer on the overwatered fertilized plots (Fig. 2 and 4). Percolate concentrations on the high N, overwatered treatments began to rise above control concentrations following an application of 28 kg N ha^{-1} in mid-July. Inorganic-N concentrations in excess of 10 mg L^{-1} were observed for the first time each summer following the August application of fertilizer on the high N treatments. Elevated concentrations were maintained through the September application each year.

The low N, overwatered treatment also generated elevated inorganic-N concentrations in late summer, although no fertilizer had been applied since late spring. Following the September application (49 kg N ha^{-1}), concentrations rose steadily until the end of each irrigation period (Fig. 2 and 4). Cisar (1986), through analysis of growth and N content of clippings, found that N uptake by Kentucky bluegrass declined in August and September. Applying N fertilizer when plant uptake is reduced could generate excess soluble N in the root zone and enhance the possibility for waterborne losses of N.

Soil-water percolation from the scheduled irrigation treatments occurred from random, large precipitation events, producing a spotty record of inorganic-N concentrations in percolate during each irrigation period. Generally, the high N, scheduled irrigation treatment generated percolate with higher inorganic N than the low and control treatments, although concentrations never approached those generated from the overwatered treatments (Fig. 2 and 4). The low N, scheduled irrigation treatment did not exhibit elevated concentrations in any of the events that occurred throughout August and early September. No percolate events were generated by precipitation in the month following the September fertilizer application, precluding evaluation of its effect on percolate concentrations on the scheduled treatments.

Event based analysis is not sufficient to evaluate the impact of N percolation from home lawns. Mean flow weighted concentrations are given in Table 2. Largely as a result of elevated concentrations during the irrigation periods, the fertilized overwatered treatments had significantly higher mean annual flow weighted concentrations than the controls. No significant differences were observed between the scheduled, fertilized treatments and the controls during any period. On all treatments, mean seasonal and annual flow weighted concentrations were well below the drinking water standard of 10 mg NO_3-N L^{-1}, suggesting that fertilizer practices in common use for home lawns do not pose a threat to potable water supplies.

Table 2. Mean flow weighted, inorganic-N concentrations in soil-water percolate.

N treatment†	Irrigation	Nonirrigation period 1 Oct. 1984–30 June 1985	Irrigation period 1 July–8 Oct. 1985	Nonirrigation period 9 Oct. 1985–1 June 1986	Irrigation period 2 June–1 Oct. 1986	Mean annual
		mg L^{-1}				
Control	Scheduled	0.50 (0.03)‡	0.24 (0.14)	0.41 (0.08)	1.49 (0.94)	0.51 (0.35)
Control	Overwatered	0.38 (0.00)	0.35 (0.03)	0.36 (0.07)	0.46 (0.19)	0.36 (0.09)
Low	Scheduled	0.46 (0.05)	0.20 (0.04)	0.52 (0.11)	3.47 (4.69)	0.87 (1.01)
Low	Overwatered	0.56 (0.15)	1.61 (0.40)	0.93 (0.36)	3.08 (1.74)	1.77 (0.87)
High	Scheduled	0.51 (0.09)	1.05 (1.68)	1.48 (1.33)	2.96 (0.55)	1.24 (0.96)
High	Overwatered	0.66 (0.20)	4.85 (0.99)	1.75 (1.31)	5.60 (1.49)	4.02 (1.01)
LSD ($P \leq 0.05$)		0.30	1.19	1.25	4.06	0.95

† Control = 0.0 kg N ha^{-1} yr^{-1}; Low = 98 kg N ha^{-1} yr^{-1}; High = 244 kg N ha^{-1} yr^{-1}.
‡ ( ) = standard deviation of three replicates.

Table 3. Annual and seasonal percolation losses of inorganic N.

N treatment†	Irrigation	Nonirrigation period 1 Oct. 1984–30 June 1985	Irrigation period 1 July–8 Oct. 1985	Nonirrigation period 9 Oct. 1985–1 June 1986	Irrigation period 2 June–1 Oct. 1986	Mean annual
		kg ha^{-1}				
Control	Scheduled	1.31 (0.10)‡	0.63 (0.39)	0.89 (0.11)	1.37 (1.10)	1.88 (1.01)
Control	Overwatered	0.98 (0.00)	2.39 (0.19)	0.79 (0.30)	2.08 (0.41)	2.79 (0.33)
Low	Scheduled	1.21 (0.36)	0.54 (0.13)	1.13 (0.10)	3.19 (3.95)	3.04 (2.91)
Low	Overwatered	1.43 (0.30)	11.00 (1.73)	2.06 (0.98)	13.81 (7.12)	13.65 (5.06)
High	Scheduled	1.34 (0.20)	2.80 (3.41)	3.24 (2.89)	2.73 (0.51)	4.87 (3.23)
High	Overwatered	1.69 (0.53)	33.17 (6.74)	3.86 (2.56)	25.15 (8.26)	31.94 (7.67)
LSD ($P \leq 0.05$)		0.77	5.64	2.74	9.30	5.04

† Control = 0.0 kg N ha^{-1} yr^{-1}; Low = 98 kg N ha^{-1} yr^{-1}; High = 244 kg N ha^{-1} yr^{-1}.
‡ ( ) = standard deviation of three replicates.

Nitrogen Percolation Losses

Mean annual and seasonal losses of N in soil-water percolate are displayed in Table 3. Mean annual losses ranged from approximately 2 kg ha^{-1} for the scheduled irrigation control treatment to 32 kg ha^{-1} for the high N, overwatered treatment.

Nitrogen losses from the fertilized plots with scheduled irrigation were not significantly different from control plots, although mean N losses from the high N, scheduled irrigation treatment were more than double the losses from the control treatment. Overwatering, however, did significantly increase N losses from fertilized plots. The low and high N overwatered treatments generated losses five- and 11-fold greater than the overwatered control plots, respectively. Most of the additional N lost from the overwatered, fertilized plots occurred during the summer irrigation period. Summer losses accounted for 88 and 91% of the annual N lost from the overwatered low and high N treatments, respectively.

Nitrogen Runoff Losses

Overland runoff occurred on only two storm events during the 2 yr of monitoring. Runoff depths are summarized in Table 1. Both of the runoff events resulted from unusual climatic conditions. Surface runoff in one of the events was generated by rainfall on frozen ground with snow cover. Extremely wet conditions preceeded the other storm (12.5 cm) that generated runoff. Although a total of 26.4 cm of precipitation occurred within 1 wk, depth of runoff was <0.2 cm.

The sandy loam soil of the study site has a high infiltration rate (SCS hydrologic group A) and is characteristic of the majority of soils overlying prime aquifers in Rhode Island. Using the SCS curve number method (SCS, 1972), a 24-h storm would have to exceed 10 cm to generate any runoff on these turf covered sites. Storms of this magnitude in Rhode Island have a return interval of 5 yr (Hershfield, 1961); therefore, overland runoff is not expected to be a major pathway for water loss from home lawns on the outwash soils of Rhode Island. On more impermeable soils, overland runoff could be expected to generate more substantial N losses.

For the two overland runoff events, concentrations of inorganic N for all the treatments ranged from 1.1 to 4.2 mg L^{-1}. Mean annual losses from overland flow ranged from 0.1 to 0.4 kg ha^{-1} hr^{-1} and comprised <7% of total waterborne loss of inorganic N from any treatment during the study.

CONCLUSIONS

Leaching losses of inorganic N from turf subjected to fertilization and watering practices associated with home lawn care do not appear to pose a threat to drinking water aquifers. Although individual events occurred that exceeded the U.S. drinking water standard, seasonal and annual flow weighted mean concentrations were always less than one-half the standard. In coastal watersheds, fertilized home lawns may contribute to the degradation of bay and estuarine water quality since substantial increases in N loadings can result from overwatered fertilized lawns.

The results of the scheduled irrigation treatments or the overwatered treatments should not be equated with the expected losses from home lawns. The irrigation regimes examined in this study represent the two extremes of home lawn water management. Currently homeowners can not be expected to schedule irrigation as carefully as this study. In practice, some degree of overwatering will occur due to the lack of homeowner knowledge regarding soil moisture status. In areas concerned with NO_3 contamination of groundwater, late summer applications could be minimized and homeowners encouraged to limit the quantity and frequency of watering. Overland runoff from turfgrass on permeable soils was not a major contributor to total inorganic-N losses.

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