Appendix A - Nitrogen Fertilizer Leaching Rate from Turfgrass Literature Summary

Title	Author(s)	Year	Journal	Purpose / Objectives	Conditions: Grass – Type	Grass – Age	Soil	Soil – Slope	Fertilization – Type	Fertilization – Rate	Fertilization – Clippings	Irrigation	Field / greenhouse	Location	Results: Leaching Rate (s)	Comments
Root Architecture Affects Nitrate Leaching from Bentgrass Turf	Bowman, Devitt, Engelke, Rufty	1998	Crop Science Society of America	Examine the effects of rooting depth and density on NO3 leaching from creeping bentgrass turf.	2 types of creeping bentgrass, shallow and deep-rooted	4 months	Medium / coarse washed sand		Ammonium nitrate	50 kg N/ha	Removed	Exp.1: 1, 2 & 3 cm/day, starting 1 day after fert. Exp.2: 2 cm/ 1-2 days, starting 1, 3, and 5 days after fert.	Greenhouse	Reno, NV	Exp.1: Shallow root: 33.8, 38.9, & 41.9% for 1, 2, & 3 cm/day Deep root: 14.5, 18.6, 22.4% for 1, 2, & 3 cm/day Exp.2: Shallow root: 17, 4, & 2% for 1, 3, & 5 day delay Deep root: 5, 0.2, and 0.1% for 1, 3, & 5 day delay	Deep-rooted turf absorbs N more efficiently than shallow-rooted turf, with similar turf densities.
Groundwater Contamination Potential of Pesticides and Fertilizers Used on the Golf Course	Branham	1993	United States Golf Association (USGA) Green Section	Monitor the movement of pesticides and fertilizers through soil and their potential to contaminate groundwater.	Kentucky bluegrass	Already established	sandy loam		urea	single application at 0.8 lb N/1,000 ft2 enriched with 25% 15N, two timings (early spring, late fall)		Yes, immediately after fertilization			spring application: 0.01% of 15N fall application: 0.005% of 15N	Thatch layer is important to the fate of N applied to turf. In both treatments, the amount of 15N in the thatch represents 25% of applied N. There may be long term build up of N in the soil. Most of the 15N found in the soil is in the top 5 cm layer.
Leaching of Nitrate from Sand Putting Greens	Brauen, Stahnke	1995	United States Golf Association (USGA) Green Section	Quantify the effect of rooting medium, fertilization interal, and annual nitrogen rate on nitrate nitrogen leached from creeping bentgrass putting greens.	Creeping bentgrass	New (includes establishment) to 1-year old	pure sand, or sand-peat-silt loam (88, 10, 2)		granular ammonium sulfate, ammonium phosphate, isobutylidene fiurea, sulfur-coated urea, and methylene urea	4, 8, 12 lb N/ 1,000 s.f./year in 11 applications from Feb to December				Puyallyp, WA (south of Seattle)	Sand 4 lb/1000sf: 0.06 - 5.37% 8 lb/1000sf: 0.04-6.31% 12 lb/1000sf: 0.7-7.55% Modified (sand/peat) 4 lb/1000sf: 0.16 - 0.33% 8 lb/1000sf: 0.02-0.91% 12 lb/1000sf: 1.26-3.37%	Precipitation was much lower in the year with the lowest N leaching results. Variations in leaching could be related to variations in precipitation. 4 lbs N/1,000 sf is insufficient to support nentgrass or bluegrass in putting greens. "Applying N fertilizers with at least 70% of the nitrogen source in slow-release form on a frequent interval such as every 14 days provided excellent protection from nitrate leaching."
Nitrate Leaching from Long Established Kentucky Bluegrass Turf *	Duff, Liu, Hull, Sawyer	1997	International Turfgrass Society Research Journal		Kentucky bluegrass	Long established			Urea	0, 10.3, 18.0, and 25.7 g/ m2/ year in 5 factional treatments	Harvested monthly			RI		Efficiency of fall N fertilizer application may be low because of abundance of nitrate in soil. Temperature and rainfall affect nitrate leaching from established turf.
Fertilizer Source Effect on Ground and Surface Water Quality in Drainage from Turfgrass	Easton, Petrovic	2004	Journal of Environmental Quality	Determine (1) if fertilizer properties and rate affect ground and surface water quality in drainage from turfgrass, and (2) what other factors can affect surface and ground water quality.	Mixed Kentucky bluegrass (80%) and perennial ryegrass (20%)	New (establishment) - 2 years	Arkport sandy loam	7-9%	compost and biosolid (natural organic), and urea and sulfur coated urea (synthetic organic)	Total: 200 kg N/ha/year 50 and 100 kg N/ha in 4 and 2 applications.	Removed	5 mm			Approximately (extrapolated from graph): 1.5-40% depending on fertilizer source and rate.	The establishment period has the highest nutrient leaching losses (12 - 80%). "Long term repeated use of natural organic sources could result in massive amounts of P and N being stored in the soil, eventually being released and subject to runoff and leaching losses."
Effects of Slow-Release Fertilizers on Growth and on Uptake and Leaching of Nutrients in Kentucky Bluegrass Turfs Established on Sand-Based Root zones *	Engelsjord, Singh	1997	Canadian Journal of Plant Science	Determine the effect of slow-release and water-soluble fertilizers on growth, nutrient uptake and leaching from a sandbased Kentucky bluegrass turf.	Kentucky bluegrass		Sand-peat mix: 80:20 and 60:40		Coated, and water soluble "NPK" treatment	Frequent application with water soluble, or spring application with slow-release				southern part of Norway	1.1 - 2.9 %	Outside the U.S. (Norway)

Title	Author(s)	Year	Journal	Purpose / Objectives	Conditions: Grass: Type	Grass: Age	Soil	Soil: Slope	Fertilization: Type	Fertilization: Rate	Fertilization: Clippings	Irrigation	Field / greenhouse	Location	Results: Leaching Rate (s)	Results: Comments
Deep Nitrate Movement in the Unsaturated Zone of a Simulated Urban Lawn	Exner, Burbach, Watts, Shearman, Spalding	1991	Journal of Environmental Quality	Record deep NO3 movement under fixed irrigation with variable N application rates.	Kentucky bluegrass and creeping red fescue	Existing (no establishment)	Bayard fine sandy loam		Ammonium nitrate NH4NO3	Fertilizer alone: 0, 1, 1.5, 2, and 2.4 kg N/100 m2 (2-5 times recommended use) Total irrigation adds ~0.5 kg N/100 m2		Starting immediately after fertilization: 51 mm every 3rd day, total of 640 mm over 34 days	Field	Sidney, NE	1 kg N/100 m2: 90% 1.5 kg N/100 m2: 93% 2 kg N/100 m2: 95% 2.4 kg N/100 m2: 83%	Uniform 8mg/L NO3-N levels in the upper 3m of unfertilized plot reflective of municipal water supply. Frequent application of excess water caused N03 fertilizer to move rapidly below the root zone. Vertical profiles showed a pulse (spike) of N corresponding to the fertlization event. NO3 in irrigation water must be accounted for as a N source.
The Fate of Nitrogen Applied to a Mature Kentucky Bluegrass Turf	Frank, O'Reilly, Crum, Calhoun	2006	Crop Science Society of America	Quantify N03-N and N04-N concentrations in leachate & determine fate of labeled fertilizer N among clippings, verdure, thatch, soil, roots and leachate for a Kentucky bluegrass turf 10-year after establishment.	Kentucky bluegrass	10 year	Marlette fine sandy loam		Urea - (NH2)2CO	Total: 98 and 245 kg N / ha in 5 applications	Returned	80% of potential evapotranspiration	Field	Hancock Turfgrass Research Center, Michigan State University	1% for low N-fertilization, 11% for high fertilization	Older turf sites should be fertilized at reduced N rate to minimize N03-N leaching. High-rate, water-soluble, nitrogen applications can cause elecated levels of NO3-N leaching from mature turfgrass.
The Effects of Establishment Methods and Fertilization Practices on Nitrate Leaching from Turfgrass	Geron, Danneberger, Traina, Logan, Street	1993	Journal of Environmental Quality	Determine the effects of turfgrass establishment method, late season fertilization and different N sources on N leaching on silt loam soil under field conditions.	Kentucky bluegrass (sodded, and seeded)	New (includes establishment)	Miamian silt loam		Urea, and resin-coated urea (120-day release)	Annual: 218 kg N / ha / yr in 5 applications: spring / summer, or including late season	Returned	yes	Field	Columbus, OH	Only concentrations were reported. Leach rates could not be calculated.	Establishment method affected leach rate: sodded turf had greater NO3-N losses than seeded turf, especially after turfgrass matured. Probably related to deeper roots. Little effect of N sources on leaching rates. Highest leach rates observed in late summer and early fall.
Movement of Nitrogen Fertilizer in a Turfgrass System	Gibeault, Yates, Meyer, Leonard	1998	California Turfgrass Culture	Monitor N movement below the root system of cool-season turfgrasses when the nutrient is applied at high rates and frequent intervals.	Mixed Kentucky bluegrass and perennial ryegrass	Mature	Hanford fine sandy loam		granular urea (soluble), sulfur-coated urea (slow release), blood meal (natural organic)	2.5 lb N / 1,000 ft2 every eight weeks (study over 2 applications)	Removed	Based on 50% moisture depletion		Riverside, CA	Not specified	Urea N source resulted in highest concentration of nitrate in leachate, peaking 10-14 days after fertilization.
Nitrate-Nitrogen Losses to Groundwater from Rural and Suburban Land Uses	Gold, DeRagon, Sullivan, Lemunyon	1990	Journal of Soil and Water Conservation	Quantify and rank nitrate-N contributions from the major land use types found in aquifer recharge zones of southern New England.		At least one year old	Merrimac sandy loam		50% urea plus 50% ureaform (liquid)	49-24-24-49-98 kg/ha over 5 applications, for total of 244 kg/ha			Field	Kingston, RI	1.9 - 9.3 kg/ha /year, or 1-4%	Other land uses compare to septic system, which showed a 21% removal (79% loss) of N by the septic tank and absorption trenches. Replacing production agriculture with unsewered residential development will not reduce N-losses to the ground water
Vadose Zone Processes and Chemical Transport	Guillard, Kopp	2004	Journal of Environmental Quality	Determine (1) NO3-N concentrations and losses from turfgrass managed as lawn from various foms of N, and (2) the season when the losses are most likely to occur.		2 years	Paxton fine sandy loam		Ammonium nitrate, coated urea, and organic product	147 kg N / ha/ yr, split into 3 applications		None	Field	Storrs, CT	Ammonium nitrate: 16.8% Coated urea: 1.7% Organic prduct: 0.6%	NO3-N losses affected by N source, and season. Lower solubility fertilizers present lower risk. Most of the NO3-N leaching occurred from late fall to early spring.
Mass Balance of 15N Applied to Kentucky Bluegrass Including Direct Measurement of Denitrification	Horgan, Branham, Mulvaney	2002	Crop Science Society of America	Determine (i) the fate of N applied to turfgrass, including direct measurement of denitrification, and (ii) whether the completeness of recovery of 15N-labeled fertilizer applied to turfgrass is influenced by the presence of plants.	Kentucky bluegrass	Established	Flanagan soil (sand, silt, clay contents: 125, 588, 287 g/kg)		Potassium nitrate	49 kg N/ha	Removed	Twice a week to replace 80% of potential evapotranspiration when rain was not sufficient	Field and greenhouse	Urbana, IL		Thatch layer collected ~25% of applied 15N. Bare soil (no turf) had similar soil N content, but leachate had 4 times greater N content.

Title	Author(s)	Year	Journal	Purpose / Objectives	Conditions: Grass: Type	Conditions: Grass: Age	Conditions: Soil	Conditions: Soil: Slope	Conditions: Fertilization: Type	Conditions: Fertilization: Rate	Conditions: Fertilization: Clippings	Conditions: Irrigation	Conditions: Field / greenhouse	Conditions: Location	Results: Leaching Rate (s)	Results: Comments
Clinoptilolite Zeolite Influence on Nitrate Leaching and Nitrogen Use Efficiency in Simulated Sand Based Golf Greens	Huang, Petrovic	1992	Journal of Environmental Quality	Determine the NO3 and NH4 leaching potential from a simulated sand putting green amended with Clinoptilolite Zeolite and the N fertilizer uptake efficiency by creeping bentgrass grown on this medium.	Creeping bentgrass	15 weeks (after establishment)	Acidic sand, & Sand mixed with Clinoptilolite Zeolite (9:1)		(NH4)2SO4	0, 98, 196, and 293 kg N/ha in 4 applications of increasing concentrations	Removed	At least once a week, to lysimeter capacity	Greenhouse		Sand: 2.8, 2.3, and 6.6% at 98, 196, and 293 kg N/ha Sand + Clinoptilolite Zeolite: 2.5, 1.1, and 0.9% at 98, 196, and 293 kg N/ha	Presence of Clinoptilolite Zeolite lowers leachate concentrations at all fertilization rates, the more N applied, the less leaching. Visual quality of turfgrass in sand (not in sand + CZ) declined with higher N app. rates, suggesting potential phytotoxicity of fertilizer.
Mobility of Soil Nitrogen and Microbial Responses Following the Sudden Death of Established Turf	Jian, Bushoven, Ford, Sawyer, Amador, Hull	2000	Journal of Environmental Quality	Quantify responses of the microbial community and the mobility of soil nitrogen following the sudden death of established turf.	Kentucky bluegrass, red fescue, perennial ryegrass, and hard fescue	10 + years, and dead	Enfield silt loam (coarse silty over sandy)		None during study - soil estimated to have ~2,250 kg N / ha	None	Returned			Kingston, RI	7% leaching from soil content (no fertilization) for dead turf, 2% for live turf. Turf species had no impact.	Not relevant, no fertilization.
Nitrogen Leaching Through a Floating Sand-Based Golf Green under Golf Course Play and Management *	Johnston, Golob, Kleene, Pan, Miltner	2001	International Turfgrass Society Research Journal	(1) Quantify N concentration and quantity in leachate, flow, and percent N recovered, and (2) Determine if microlysimeter data correlate with that obtained from the whole-green system.			Sand			0.5 g N/m2 every 7-10 days, additional applications of 1.5 - 4.5 g N/m2			Field	Coeur d'Alene, ID		
Clipping Contributions to Nitrate Leaching from Creeping Bentgrass under varying Irrigation and N Rates	Kopp, Guillard	2005	International Turfgrass Society Research Journal	Determine combined effects of clipping management, irrigation, and N fertilizer rate on nitrate leaching from creeping bentgrass.	Creeping bentgrass	6 months	Agawam fine sandy loam (60% sand, 30% silt, 10% clay)		Aqueous NH4NO3	4 rates from 0 to 392 kg N/ ha split in 3 applications	Returned and Removed	Standard (S) and Standard +precip (S+P)	Greenhouse	Storrs, CT	Removed clippings: Standard irrig.: 0.9 - 7.6% S+P irrig: 14.3 - 41.8% Returned clippings: Standard irrig.: 12.8 - 23.6% S+P irrig: 39.2 - 62.9%	Delays observed between the time of fertilization and the appearance of peak NO3-N concentrations.
Comparing Cultivars of Three Cool-Season Turfgrasses for Soil Water NO3 Concentration and Leaching Potential	Liu, Hull, Duff	1997	Crop Science Society of America	Compare three cool-season turfgrasses for their relative NO3 leaching potential as determined by (i) seasonal NO3-N concentrations in leachate from each grass, and (ii) total seasonal N03-N leached per unit area under each grass.	10 cultivars of Kentucky bluegrass, perennial ryegrass, and tall fescue	3-5 years at beginning of 2-year study	Enfield silt loam (coarse loamy over sandy)		50% inorganic ammonium nitrae, 50% urea and methyl urea	149 kg N/ha/yr in 3 applications of 49.7 kg N/ha	Returned		Field	Kingston, RI	Kentucky bluegrass: 7% in year 1, 14% in year 2 across 10 cultivars, with much variability (up to five fold) and up to 30% leaching for the Liberty cultivar Perennial ryegrass: 2% in year 1, 4.8% in year 2 across cultivars, varying from 1.5 - 14% Tall Fescue: 0.8% in year 1, 1.4% in year 2 across 10 cultivars, with much variability (up to five fold)	Hydrologic model built to determine soil moisture content on daily basis. For Kentucky bluegrass and perennial ryegrass, the greatest losses occurred in December, ranging from 20 to 80%, and 10-50% of the annual loss, respectively. Differences between turfgrasses influence N leaching.
Nitrate and Ammonium Leachin Losses from N Fertilizers Applied to 'Penncross' Creeping Bentgrass	Mancino, Troll	1990	HortScience	Quantify maximum leaching losses of NO3 and NO4 N from green turf receiving weekly and biweekly light to moderate N applications coupled with thice weekly heavy irrigation.	Penncross' creeping bentgrass	10 months	Sand-peat (80:20)		Calcium nitrate, ammonium nitrate, ammonium sulfate, urea, urea formaldehyde, and isobutylediene urea	Over 10 weeks: * 9.76 kg N/ha per 7 days * 19.52 kg N/ha per 14 days Single application: 48.8 kg N/ha	Removed	38 mm/ week	Greenhouse		Over 10 weeks: 0.0 to 0.2% for 9.76 kg N/ha 0.0 to 0.32% for 19.52 kg N/ha Single application: 0.0 to 4.13 %	Highest leaching occurred from NH4NO3 source for single and multiple fertilizer applications. Urea N source showed no leaching. Ammonium N leaching was negligible in all leachate.
Nitrate Leaching from Kentucky Bluegrass Soil Columns Predicted with Anion Exchange Membranes (AEMs)	Mangiafico, Guillard	2007	Soil Science Society of America	Determine if soil NO3-N desorbed from AEMs might serve as predictor of N03-N leaching from turfgrass.	Kentucky bluegrass	New (includes establishment)	Agawam fine sandy loam		Aqueous NH4NO3	16 rates from 0 to 587 kg N /ha/yr		2.5 cm/ week	Greenhouse	Storrs, CT	7 - 28%	Leaching rates may be high, because leaching for zero N application treatment was significant. May be due to differences in N mineralization potential of soil.

					Conditions										Results	
Title	Author(s)	Year	Journal	Purpose / Objectives	Grass		Soil		Fertilization			Irrigation	Field / greenhouse	Location	Leaching Rate (s)	Comments
					Type	Age		Slope	Type	Rate	Clippings					
Fall Fertilization Timing Effects on Nitrate Leaching and Turfgrass Color and Growth	Mangiafico, Guillard	2006	Journal of Environmental Quality	Investigate the timing effects of fall fertilization on both leaching losses and turfgrass color, density, root mass, and clipping yield for a turf stand in southern New England under a home lawn management practice.	90% Kentucky bluegrass, 10% creeping red fescue lawn	sodded in the first summer (excluded from results) of a 3-year experiment	Loamy sand under 20 cm of topsoil (loamy sand)		<u>Spring, and summer</u>: 60% NH4, 40% urea <u>Fall</u>: 9% Nh4, 74% urea, and 17% water insoluble	49 kg N/ha each of 3 applications for a total of 147 kg N/ha for fertilized plot, 98 kg N/ha for control	Returned	2.5 cm/ week May to September	Field	Storrs, CT	<u>Year 1</u>: 1.6 - 16.8% (warmer, +3.5 deg C, and drier than normal, -46% precip) <u>Year 2</u>: 29.1-66.1% (-1.2 deg C vs. normal, -1% precip vs. normal)	NO3 concentrations above 40 mg/L were observed during establishment, and data were removed from results. "Mean cumulative NO3-N mass collected in percolate water was significantly linearly correlated to the date of fertilization. The later the date of application of fall fertilization, the more NO3-N was collected in the perclate water."
Leaching and Mass Balance of 15N-Labeled Urea Applied to a Kentucky Bluegrass Turf	Miltner, Branham, Paul, Rieke	1996	Crop Science Society of America	Construct a mass balance for the fertilizer nitrogen applied to turf in the early spring or late fall, paying special attention to quantitative leachate collection, soil transformation, plant uptake, and soil microbial activity.	Kentucky bluegrass	6 months	Marlette fine sany loam		urea	5 equal apps at 38 day intervals of 39.2 kg N/ha for total of 196 kg N/ha/yr, 1 using 15N	Removed	Total of 56 cm irrigation in addition to 218 cm of precipitation	field		<u>spring application</u>: 0.23% of 15N <u>fall application</u>: 0.18% of 15N	Thatch was a significant sink for the labeled N (15N). Soil 15N increased over 1 year, following decreased thatch 15N, indicating possible downward movement of mineralized 15N from thatch. Late fall application resulted in greater N leaching, which was still small.
Nitrogen Uptake and Leaching under Annual Bluegrass Ecotypes and Bentgrass Species: A Lysimeter Experiment	Paré, Chantigny, Carey, Johnston, Dionne	2006	Crop Science Society of America	Compare N-uptake and potential mineral leaching among various annual bluegrass ecotypes and bentgrass species.	11 annual bluegrass ecotypes, 3 bentgrass species	3.5 months	Sand-peat mix (similar to golf green)		Water-soluble NH4NO3	4 applications of 25 kgN / ha (equivalent to 350 kg N/ha/yr		1.9 cm every other day	Greenhouse	Guelph, ON, Canada	6 - 71% Bentgrass: 6-11% Bluegrass: 28-71%	Greatest leaching in unplanted control, with losses at 116% of applied N. May be due to exp. Error, or mineralization and subsequent leaching
Nitrogen Source and Timing Impact on Nitrate Leaching from Turf	Petrovic	2004	Acta Horticulturae	Determine effect of N source and timing on NO3 leaching from Kentucky bluegrass.	Kentucky bluegrass	2-4 years	Sandy soils: sand: 51-67% silt: 17-36% clay: 16-21%	< 2%	water soluble (urea) and slow release (coated urea, biosolid, urea-formaldehydes)	9.8 and 19.7 g N/m2 in 1 - 4 applications			Field	Riverhead, St. Charles, and Ithaca, NY	<u>Normal precipitation</u>: Water-soluble N: 0.9-5% Slow release N: 0.5-7.4% <u>291 mm above normal precip</u> Water-soluble N: 12-29% Slow release N: 2-7% <u>N at end of growing season</u>: Water-soluble N: 29-47% Slow release N: 0-12%	N losses with applications in the late fall result in high leaching rates.
Impact of Soil Texture on Nutrient Fate	Petrovic	2004	Acta Horticulturae	Determine if (i) soils with water flow rates either have a larger proportion of leaching through soil or at least have more leaching under very wet conditions, (ii) more nutrient recovery in the plant could mean less nutrient available for leahing loss, (iii) and nutrient accumulation in soil, as part of soil organic matter, including roots, is much faster at a low initial organic matter content.	Creeping bentgrass		sand, sandy loam, and silt loam		urea-methylene urea	150 kg N/ha /year in applications of 48 kg N/ha	Removed	Rainfall controlled by rainout shelter, simulated rain pattern used (min 25 mm per week)	Field	Ithaca, NY	<u>sand</u>: 9.1% <u>sandy loam</u>: 1.5% <u>silt loam</u>: 3.5%	Most of the N recovery was in the clippings for sandy loam (52%), and silt loam (91%) compared to sand (8%). No measurable N from fertilizer applied was found in sandy or silt loam. Nitrate concentrations in leachate were high during establishment in only 2 samples from sand lysimeters. More water leached from sand than other soils. Because of the high amount of fertilizer found in the clippings, "care must be given on where clippings are disposed."

Title	Author(s)	Year	Journal	Purpose / Objectives	Conditions										Results	
					Grass		Soil		Fertilization			Irrigation	Field / greenhouse	Location	Leaching Rate (s)	Comments
					Type	Age		Slope	Type	Rate	Clippings					
Timing of Nitrate Leaching from Turfgrass after Multiple Fertilizer Applications	Roy, Parkin, Wagner-Riddle	2000	Water Quality Research Journal of Canada	Determine the contribution of N applied in May, July, and September to leaching.	Kentucky bluegrass	sodded	25 cm sandy loam, over 25 cm loamy sand, over sand		Ammonium nitrate	154 kg N/ha /year in three applications	Returned		Field	Guelph, ON, Canada	average of 16.5% of applied nitrogen, with up to 21% but sampling stopped in mid-December due to snow and cold, at which time N concentrations in the leachate were still high.	Very little leaching occurred in the spring and summer months (following fertilization), probably limited by the precipitation and evapotranspiration rates. By early winter, lysimeters had los up to 21% of the applied nitrogen. "For fertilizer applied under similar conditions, nitrogen remaining in the soil profile may be washed out in the autumn (...) The chances of detecting the contamination with regular water testing are not great, however, since the contamination is arriving in a single pulse."
Fate of Amended Urea in Turfgrass Biosystems	Starrett, Christians, Austin	1995	Communications in Soil Science and Plant Analysis	(i) Investigate the hydrology of 20cm diameter by 50cm deep undisturbed soil columns covered with a Kentucky bluegrass turf under a heavy (one 2.5 cm application) and a light (four 0.64 cm applications) irrigation regime, and (ii) quantify the fate of 15-N labeled urea when it is applied to an undisturbed soil column having intact macropores.	Kentucky bluegrass						Removed	heavy (one 2.5 cm application) and a light (four 0.64 cm applications) irrigation regime				"The heavy irrigation regime significantly increased the transport of N below 30cm by 5 times, compared with the light irrgation regime. 85% of the N found in the leachate from the 50cm columns was in the urea form indicating that macropores may have played a major role in transport of surface applied N through the soil profile."

* Only abstract was reviewed. Article not available

Appendix B – Bayberry Hills Golf Course Data (2000 – 2008)

This Appendix provides detailed data reported by the Bayberry Hills golf course, in West Yarmouth, MA, including water quality measurements under certain greens and fairways. Table B1 provides the nitrogen concentrations measured in lysimeters under three greens, and expressed in milligrams per Liter (mg/L). Another three data tables are provided in this Appendix.

Table B1. Nitrogen Concentration Measurements in Lysimeters under Three Greens

13 Green		9 Green		7 Green	
Date	**Total Nitrogen (mg/L)**	**Date**	**Total Nitrogen (mg/L)**	**Date**	**Total Nitrogen (mg/L)**
2/9/2000	4.4	2/9/2000	2.1	2/9/2000	4.4
10/4/2000		10/4/2000		10/4/2000	
12/5/2000		12/5/2000	8.18	12/5/2000	20.95
4/3/2001	2.58	4/3/2001	2.36	4/3/2001	2.19
7/12/2001		7/12/2001	26.6	7/12/2001	6.12
12/17/2001	24.2	12/17/2001	13.5	12/17/2001	6.04
3/28/2002	3.19	3/28/2002	1.94	3/28/2002	2.3
6/12/2002	3.5	6/12/2002	5.14	6/12/2002	4.73
9/27/2002	16.7	9/27/2002	18.3	9/27/2002	13.2
4/4/2003	2.26	4/4/2003	1.83	4/4/2003	2.65
6/20/2003	3.65	6/20/2003	5.4	6/20/2003	3.93
10/7/2003	18.8	10/7/2003	6.92	10/7/2003	12.7
3/25/2004	3.5	3/25/2004	4.77	3/25/2004	4.24
4/1/2004	1.89	4/1/2004	1.51	4/1/2004	0.75
6/24/2004	3.24	6/24/2004	3.24	6/24/2004	0.84
9/27/2004	11.6	9/27/2004	3.38	9/27/2004	9.38
11/24/2004	4.12	11/24/2004	2.08	11/24/2004	3.32
4/7/2006	2.9	4/7/2006	4.4	4/7/2006	4.8
9/1/2006	11.2	9/1/2006	6	9/1/2006	9.8
5/18/2007	1.9	5/18/2007	2.9	5/18/2007	5.6
10/5/2007	18.2	10/5/2007	4.9	10/5/2007	7.2
4/29/2008	3	4/29/2008	2.5	4/29/2008	4.6
12/2/2008	3.8	12/2/2008	3.2	12/2/2008	3.6
Average	**7.23**	**Average**	**5.96**	**Average**	**6.06**

Table B2 provides the annual averages of the concentration measurements under the same greens, calculated based on data points from Table B1.

Table B2. Annual Average Nitrogen Concentrations in Lysimeters under Three Greens

13 Green		9 Green		7 Green	
Year	**Annual Average Nitrogen Concentration (mg/L)**	**Year**	**Annual Average Nitrogen Concentration (mg/L)**	**Year**	**Annual Average Nitrogen Concentration (mg/L)**
2000	4.40	2000	5.14	2000	12.68
2001	13.39	2001	14.15	2001	4.78
2002	7.80	2002	8.46	2002	6.74
2003	8.24	2003	4.72	2003	6.43
2004	4.87	2004	3.00	2004	3.71
2006	7.05	2006	5.20	2006	7.30
2007	10.05	2007	3.90	2007	6.40
2008	3.40	2008	2.85	2008	4.10
Average	**7.40**	**Average**	**5.93**	**Average**	**6.52**

Table B3 provides the nitrogen concentrations measured in lysimeters under three fairways from the Bayberry Hills golf course, and expressed in milligrams per Liter (mg/L).

Table B3. Nitrogen Concentration Measurements in Lysimeters under Three Fairways

13 Fairway		9 Fairway		7 Fairway	
Date	**Total Nitrogen (mg/L)**	**Date**	**Total Nitrogen (mg/L)**	**Date**	**Total Nitrogen (mg/L)**
2/9/2000	3.2	2/9/2000	4.4	2/9/2000	
10/4/2000		10/4/2000		10/4/2000	
12/5/2000	2.81	12/5/2000	5.05	12/5/2000	3.18
4/3/2001	2.05	4/3/2001	1.92	4/3/2001	1.49
7/12/2001	5.76	7/12/2001	5.11	7/12/2001	4.96
12/17/2001	10.5	12/17/2001	4.44	12/17/2001	28.2
3/28/2002	1.79	3/28/2002	2.26	3/28/2002	2.1
6/12/2002	5.88	6/12/2002	7.14	6/12/2002	5.88
9/27/2002	11.7	9/27/2002	8.61	9/27/2002	9
4/4/2003	1.08	4/4/2003	1.91	4/4/2003	1.56
6/20/2003	9.42	6/20/2003	5.52	6/20/2003	2.79
10/7/2003	8.5	10/7/2003	19.2	10/7/2003	12.9
3/25/2004	1.12	3/25/2004	4.12	3/25/2004	3.43
4/1/2004	2.36	4/1/2004	2.72	4/1/2004	1.35
6/24/2004	2.44	6/24/2004	2.5	6/24/2004	1.22
9/27/2004	16	9/27/2004	59	9/27/2004	16.1
11/24/2004	4.5	11/24/2004	8.45	11/24/2004	6.02
4/7/2006	1.5	4/7/2006	2.4	4/7/2006	4.1
9/1/2006	11	9/1/2006	5.7	9/1/2006	18.4
5/18/2007	3.4	5/18/2007	1.3	5/18/2007	4.8
10/5/2007	10.4	10/5/2007	29.3	10/5/2007	19.8
4/29/2008	5.9	4/29/2008	3.5	4/29/2008	4.3
12/2/2008	1.6	12/2/2008	3	12/2/2008	1.8
Average	**5.59**	**Average**	**8.53**	**Average**	**7.30**

Table B4 provides the annual averages of the concentration measurements under the same fairways, calculated based on data points from Table B3.

Table B4. Annual Average Nitrogen Concentrations in Lysimeters under Three Fairways

13 Fairway		9 Fairway		7 Fairway	
Year	**Annual Average Nitrogen Concentration (mg/L)**	**Year**	**Annual Average Nitrogen Concentration (mg/L)**	**Year**	**Annual Average Nitrogen Concentration (mg/L)**
2000	3.01	2000	4.73	2000	3.18
2001	6.10	2001	3.82	2001	11.55
2002	6.46	2002	6.00	2002	5.66
2003	6.33	2003	8.88	2003	5.75
2004	5.28	2004	15.36	2004	5.62
2006	6.25	2006	4.05	2006	11.25
2007	6.90	2007	15.30	2007	12.30
2008	3.75	2008	3.25	2008	3.05
Average	**5.51**	**Average**	**7.67**	**Average**	**7.30**