Quantification and Fate of Nitrogen from Amended and Trafficked Sand Putting Green/Tee Profiles

Executive Summary

Experimental putting greens that were constructed close to USGA specifications were monitored for concentration of nitrate-N in percolates from October, 1991 to October 1993. The concentration of nitrate-N percolated from the profiles was rate related and the extent of concentration of nitrate-N percolated was strongly modified by the rooting medium and frequency of nitrogen (N) application during the first year.

In that year, the concentration of nitrate-N percolated from pure sand profiles was much greater than the nitrate-N leached from sand profiles modified with peat moss. Modified sand greatly reduced the quantity of total N lost and the percentage of applied N that was lost as compared to pure sand for a 99-day period from October 24, 1991 to February 1, 1992. The frequency of application of N during the first year significantly affected the level of nitrate-N lost. Although the impact of this factor was much lower than either N rate or rooting medium effects, it did consistently influence nitrate-N concentration in the percolate. The use of modified sand rooting medium, moderate levels of total annual N application and frequent application of N combined to reduce N lost in percolates to 3 to 4 kg ha^{-1} (2.67 to 3.56 lb A^{-1}) and the percentage of applied N lost in percolates to as low as 3 to 5%.

In the second year, nitrate-N concentration in the percolates was greatly reduced compared to year one. A significant part of this major change was attributed to more extensive rooting, increase in thatch and increase in organic matter in the root profiles. The concentration of nitrate-N percolated again was rate related but the extent of concentration of nitrate-N lost was not strongly modified by the rooting medium or frequency of N application. The concentration of nitrate-N percolated from pure sand profiles was similar to that percolated from modified sand profiles most of the year. In addition, the reduced concentration of nitrate-N in percolates was attributed to a greater quantity of precipitation (56 mm) during early spring in 1993 as compared to 1992 resulting in dilution of percolate nitrate-N concentration. Nearly zero concentration of nitrates were observed in percolates in summer or fall until December. Quantitative assessment of nitrate-N lost daily through leaching via nitrate-N could not be completed in time for this report.

Quantification and Fate of Nitrogen from Amended and Trafficked Sand Putting Green/Tee Profiles

An Annual Report Submitted to the USGA Research Committee

October 29, 1993

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RESEARCH PROGRESS

Thirty-six research lysimeters were monitored since November of 1991 for nitrate-N moving in percolates from lysimeters simulating golf greens constructed close to USGA construction specification guidelines. These lysimeters were 1.2 x 2.48 in size, each constructed with chlorosulfonated polyethylene reinforced liner, and fitted with 3.75 mm ABS perforated drain tubes. The drain tubes were overlaid by 8 cm of pea-sized gravel and 8 cm of course sand. Thirty-two cm of pure sand or peat amended sand (88% sand, 10% peat, 2% sandy loam [Fluvaquentic Haploxerolls]) was placed over the coarse sand and seeded on October 3, 1991 to 'Putter' creeping bentgrass. Fertilization treatments, consisting of two application timings (14 or 28 days apart) and three annual nitrogen (N) fertilization rates (195.3, 390.6 and 585.9 kg N ha^{-1} annually) were begun on October 10, 1991 (Table 1). The research area was mist-irrigated from seeding time on October 3 to October 24 to provide uniform establishment of the bentgrass and not allow percolates to flow from the lysimeters. The first rainfall occurred on October 24 1991 and percolates were collected beginning on October 25.

Percolate volumes were measured and samples collected daily throughout the fall, winter, spring and summer months of 1991-93 except on days when percolate volume was too small for sampling. Sampling occurred on four occasions during the summer of 1992 when rainfall exceeded turfgrass water use. No percolates were generated by excessive irrigation during this summer period. Fall leachate collection began in mid-October and occurred almost daily through the fall and winter of 1992 until February when very little rain fell. This is an unusual condition for western Washington. Then precipitation occurred on a regular basis until late spring. Enough precipitation occurred during the early summer to produce percolates on about half the days until early July 1993. Some excessive irrigation occurred during mid-July to produce percolates for a two-week period. No percolates occurred during August, September or early October 1993.

Percolate volumes were measured daily and leachate samples for nitrate-N and ammonium-N were preserved in 2 M KCl and held in 25 ml vials for analysis by segmented flow analysis (SFA). Approximately 12000 samples have been collected and analyzed by SFA for nitrate-N and ammonium-N at this time. All nitrate data has been entered on computer file and in the process of being developed into a thesis by graduate student, Eric Chapman. Quantification of nitrate-N leached has been estimated from percolate volumes and nitrate-N content of the percolates collected for the period from October 24, 1991 to February 1, 1992.

Table 1. Quantity of soluble and slow release N applied at each fertilizer application interval.

Nitrogen Rate	Annual Rate (lb N/1000 sq ft)					
	4		8		12	
	Eleven Monthly Applications (lb N/1000 sq ft)[2]					
Ammonium phosphate	0.04	(1.95)	0.04	(1.95)	0.04	(1.95)
Ammonium sulfate	0.20	(9.77)	0.20	(9.77)	0.20	(9.77)
Urea	0.02	(0.98)	0.07	(3.42)	0.13	(6.35)
Slow release[1]	0.10	(4.88)	0.41	(20.02)	0.72	(35.15)
Total Application	0.36	(17.58)	0.72	(35.16)	1.09	(53.22)
	Twenty-two 'Two Week' Applications (lb N/1000 sq ft)[2]					
Ammonium phosphate	0.02	(0.97)	0.02	(0.97)	0.02	(0.97)
Ammonium sulfate	0.10	(4.88)	0.10	(4.88)	0.10	(4.88)
Urea	0.01	(0.49)	0.04	(1.95)	0.07	(3.42)
Slow release[1]	0.05	(2.44)	0.20	(9.77)	0.36	(17.58)
Total Application	0.18	(8.78)	0.36	(17.58)	0.54	(26.85)

[1] Slow release nitrogen sources consisted of methylene urea, sulfur coated urea and IBDU supplied in quantities to provide equal parts N from each slow release source. Potassium was supplied from potassium sulfate as a part of the mix.

[2] Values in parenthesis equal kg N ha^{-1}.

In addition, two 50 ml leachate samples were preserved from each daily collection period for each treatment. One was preserved with boric acid to pH 2.0 for analysis with an Orion Model 290A pH/ISE meter equipped with a nitrate ion specific electrode (NISE). The data derived from NISA and SFA analysis was compared during two collection periods during the late fall and winter of 1991-92. A comparison of these methods was reported in the International Turfgrass Research Conference Journal in 1993 (Chapman, 1993). The remaining sample was preserved with concentrated sulfuric acid to pH 2.0 for analysis with an ammonium ion specific electrode (AISE). Because this method is very slow, collection of the 50 ml samples for ammonium were discontinued after late December 1991.

Plots were mowed five-times weekly with leaf growth collected once weekly. Leaf growth samples collected to estimate vegetative biomass growth and uptake of nitrogen were weighed, ground and analyzed for total nitrogen (Keeney and Nelson,

1982) during the past year . Lysimeters were sampled for rooting medium organic matter content and root dry matter, and root length, width and area (Pan & Bolton, 1991). Visual estimates of turf quality and diseases were conducted on a regular basis. The research area was sanded lightly (2.5 l m^{2} $^{-1}$) on 3 week intervals from April to October and received simulated golf shoe traffic four times weekly with a modified Brinkman traffic simulator with the differential roller torque disengaged.

RESULTS

Nitrate-N Concentration in Percolates

Attached are figures that show the average monthly concentration of nitrate-N percolating from the profiles of lysimeters from October 10 1991 to August 1993. The concentration of nitrate-N percolating from the lysimeters during the first fall, winter and spring following construction and seeding was considerably different than the concentrations of nitrate-N percolated during the second fall, winter and spring after the turf had matured. This difference is illustrated in Figures 1-5.

The average monthly nitrate-N concentration of percolate from pure sand rooting medium was significantly greater than the percolate concentration from modified sand rooting medium during November, December, March, April, May and June. The average monthly values were often quite high during the spring of 1992 although the volumes of leachate was low due to low precipitation (Fig 1.). This was not the case in the second year when average monthly concentrations were much lower during the fall and spring.

Also, average monthly concentrations of nitrate-N from pure sand rooting medium was not greatly different than concentrations from modified rooting medium. In fact, concentrations from modified rooting medium tended to be slightly higher than those from pure sand medium (Fig 1.) Where there was a strong advantage to frequently apply N at low rates which resulted in reduced levels of average monthly nitrate-N concentration in the percolates in 1992, more frequent application of N in 1993 did not have that effect except in January (Fig 2 and 4.).

Where all N rates showed significant concentrations of nitrate-N leaching in the first year, only the highest rate (585.9 kg ha^{-1}) showed significant nitrate-N concentrations in the leachates during the winter and spring periods in 1993 (Fig 3). The lower annual N rates of 195.3 and 390.6 kg ha^{-1} showed very low concentrations of nitrate-N in percolates at any time during 1993. It was also the higher rate that showed the slightly higher concentration on nitrate-N in percolates from modified sand as compared to pure sand although these levels in the modified sand were no higher than they were in 1992.

The major difference that occurred was due to the very large reduction in nitrate-N concentration in percolates from the pure sand lysimeters. The reason for these differences is not readily apparent at this time but it could be due to higher biological activity in the amended profiles as compared to pure sand profiles, higer volatilization of urea during a dry, bright February, or it could be due to slightly higher leaching of free urea from the sand profiles during this year's higher level of early spring and mid-spring precipitation.

Since the N rate increase was applied as a combination of slow release N forms which have some immediately soluble urea available at application time, cool or cold temperature rainfall events may have leached this urea in pure sand before it was converted to plant available forms. This could result in lower concentrations of nitrate-N in percolates from these lysimeters later in the spring.

The pattern of rainfall was significantly different during the winter and early spring of 1993 as compared to 1992 (Table 2). Precipitation occurred early in January in 1992 resulting in very low levels of nitrate-N concentration in percolates during January and February. Precipitation was considerably lower in March and early April in 1992 as compared to 1993 which may have resulted in lower volume of percolates and higher concentration of nitrate-N in 1992. These differences may also reflect the differences in maturity of the rooting mediums and the accumulation of organic matter in the rooting medium. Organic matter analysis being conducted by Mr. Chapman as a part of his thesis and quantification of total soluble N percolated will assist in interpretation of N dynamics in this study. Some assessment is also being conducted to identify the loss of urea through these profiles.

Table 2. Monthly Precipitation at Puyallup Lysimeter Research Site[1] from January to September during 1992 and 1993.

Month	Year [2]			
	1992		1993	
	----------- inch		------------	
January	6.03	(153)	3.45	(88)
February	3.14	(80)	0.33	(08)
March	2.16	(55)	3.87	(98)
April	4.37	(111)	4.74	(120)
May	0.52	(13)	0.58	(15)
June	2.08	(53)	1.46	(37)
July	1.61	(41)	0.13	(03)
August	0.85	(22)	0.00	(00)
September	1.78	(45)	0.00	(00)
October	1.21	(31)	----	--
November	6.54	(166)	----	--
December	3.16	(80)	----	--
Total	33.40	(848)	14.56	(370)

1 Tipping bucket rain gauge recorded 30 ft from research lysimeters.
2 Values in parenthesis equal mm precipitation.

For the second year, almost no nitrate-N was found in the percolates of any treatment combination during the summer through mid-fall. In 1972 as compared to 1991, nitrates did not appear in the percolates until mid-December which suggests the root systems of bentgrass remain very active in uptake of N well in late fall. November N fertilization at moderate rates did not result in leaching of nitrate-N.

Quantity of Nitrate-N Leached

Table 3 summarizes the quantity of nitrate-N percolated as a percentage of applied N to turfs during the first 99 days after leachate collections occurred in 1991. An average of 11.2 kg ha^{-1} (9.97 lb A^{-1}) of nitrate-N leached from sand profiles during the 99 day period while 6.0 kg ha^{-1} (5.34 lb A^{-1}) leached from modified sand profiles. However, the range of nitrate-N leached from sand profiles was from a low of 6.1 kg ha^{-1} (5.4 lb A^{-1}) where fertilizer was applied at 8.86 kg ha^{-1} (0.18 lb 1000 sq ft^{-1}) every two weeks to 18.8 kg ha^{-1} (16.7 lb A^{-1}) leached where fertilizer was applied at 53 kg ha^{-1} (1.09 lb 1000 sq ft^{-1}) every four weeks. Only 1.16 kg ha^{-1} (1.1 lb A^{-1}) of nitrogen was leached during the 99 days where fertilizer was applied at 8.8 kg ha^{-1} (0.18 lb 1000 sq ft^{-1}) at two week intervals. This level of nitrogen application was insufficient to support bentgrass or annual bluegrass growth in putting greens under play in the Northwest, but 17.6 kg ha^{-1} (0.36 lb 1000 sq ft^{-1}) at two week intervals may be adequate. At this level of fertilization each 14 days, 3.04 kg nitrate-N ha^{-1} (2.7 lb A^{-1}) was leached and this was only 2.09% of the nitrogen applied. These data represent very young and immature turf which would be strongly subject to nitrate-N movement because of the lack of a mature root system to utilize available nitrate. Processing of data from the 1992-93 winter season has not been completed but the quantities leached were very much reduced.

Table 3. Percent of nitrogen applied to turfgrass that leached as nitrate-N during 99 days after seeding.

Nitrogen[1] Application	Sand	Modified Sand
	------- % -------	
Monthly	12.0	4.9
Two Week	9.7	2.1

[1] Nitrogen applied at 97.7 kg ha^{-1} (2 lb 1000 sq ft^{-1}) during mid to late fall. Leachate measured daily through fall and winter.

REPORTS OF STUDIES

Presentations and publication of preliminary results from these studies have been provided at the Northwest Turfgrass Association Annual Conference in 1992 and 1993, the International Turfgrass Research Conference in 1993, and the Western Canada Turfgrass Association Annual Conference in 1993 and the USGA Regional Meetings in 1992. The following publications are available.

Ekuan, A.J.A. and S.E. Brauen. 1992. Determination of nitrate concentration in soil leachate with nitrate electrode. Proc. 46th Northwest Turfgrass Conference 46:12-15. Sunriver Lodge and Resort, Sunriver, OR. September 21-24, 1992.

Chapman, J.E., W.J. Johnston, S.E. Brauen, and G.K. Stahnke. 1992. Measuring nitrate movement in sand and modified root zones. Proc. 46th Northwest Turfgrass Conference 46:16-24. Sunriver Lodge and Resort, Sunriver, OR. September 21-24, 1992.

Brauen, S.E., G.K. Stahnke, C. Cogger, G. Chastagner, W.J. Johnston, and E. Chapman. Puyallup Lysimeters: Measuring nitrate movement in sand and modified sand rootzones. Turfline News 116:10-16. (Proc. Western Canada Turfgrass Association., Westin Bayshore Inn, Vancouver, B.C. CANADA, February 21-24, 1993.

Chapman, J.E., S.E. Brauen, G.K. Stahnke, W.J. Johnston. 1993. Comparison of Nitrate Ion Specific Electrode, Segmented Flow Analysis Techniques for Determining Nitrate Levels in Putting Green [Chapter 79] p. 560-564. *In* R.N. Carrow, N.E. Christians, R.C. Shearman (eds.). International Turfgrass Society Research Journal 7. Intertec Publishing Corp., Overland Park, Kansas. 1993.

Chapman, J.E., S.E. Brauen, G.K. Stahnke, W.J. Johnston. 1993. Leachate Update. Proc. 47th Northwest Turfgrass Conference 47: Yakima Holiday Inn. Yakima, WA October 11-13, 1993. (In Press)

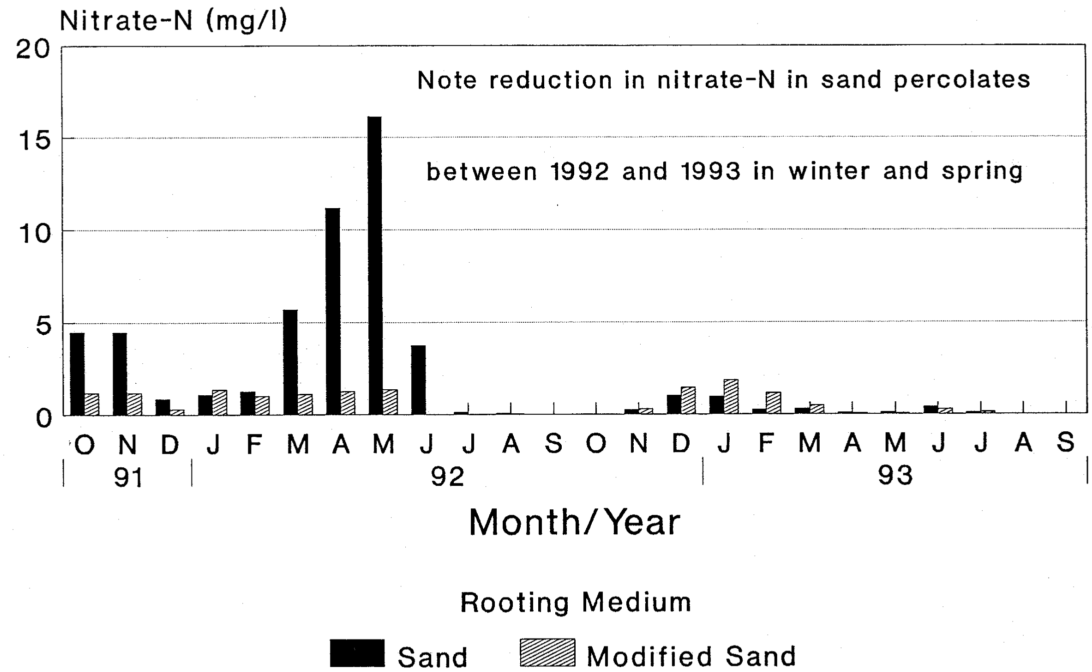
REFERENCES

Chapman, J.E., S.E. Brauen, G.K. Stahnke, W.J. Johnston. 1993. Comparison of Nitrate Ion Specific Electrode, Segmented Flow Analysis Techniques for Determining Nitrate Levels in Putting Green [Chapter 79] p. 560-564. *In* R.N. Carrow, N.E. Christians, R.C. Shearman (eds.). International Turfgrass Society Research Journal 7. Intertec Publishing Corp., Overland Park, Kansas. 1993.

Kenney, D.R., and D.W. Nelson. 1982. Nitrogen - Inorganic Forms. p. 643-698. *In* A.L. Page et al. (ed.) Methods of Soil Analysis. 2nd ed. Part 2. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

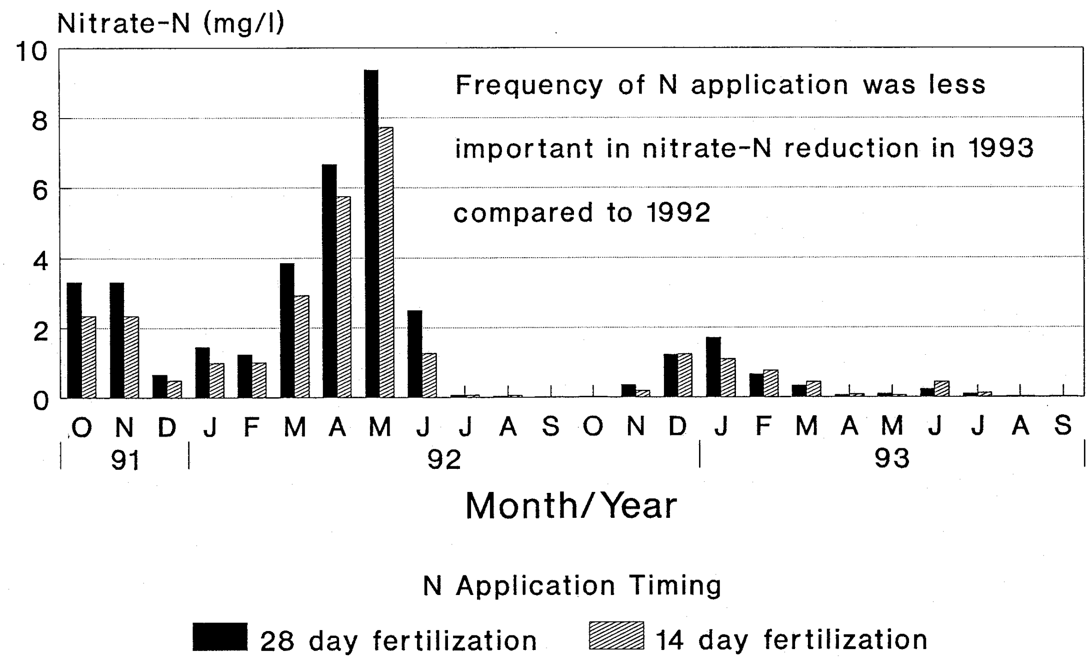
Pan, W.L., and R.P. Bolton. 1991. Root Quantification by Edge Discrimination Using a Desktop Scanner. Agron. J. 83(6):1047-1052.

Fig 1. Average Monthly Nitrate-N in Percolates from Sand vs Modified Sand



Averaged Over N Rate and Applic. Timing

Fig 2. Average Monthly Nitrate-N in Percolates on 14 or 28 Day Fertilization



Average over Root Mix and N Rate

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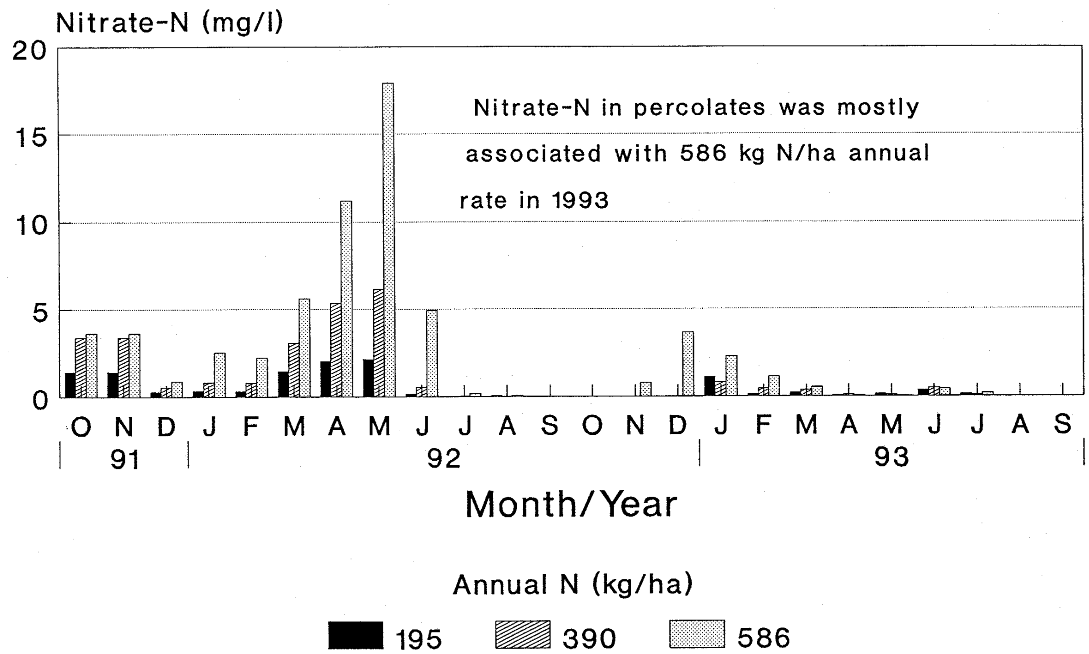
Fig 3. Average Monthly Nitrate-N in Percolates for Three Annual N Rates



Averaged over Rooting Mix and N Timing

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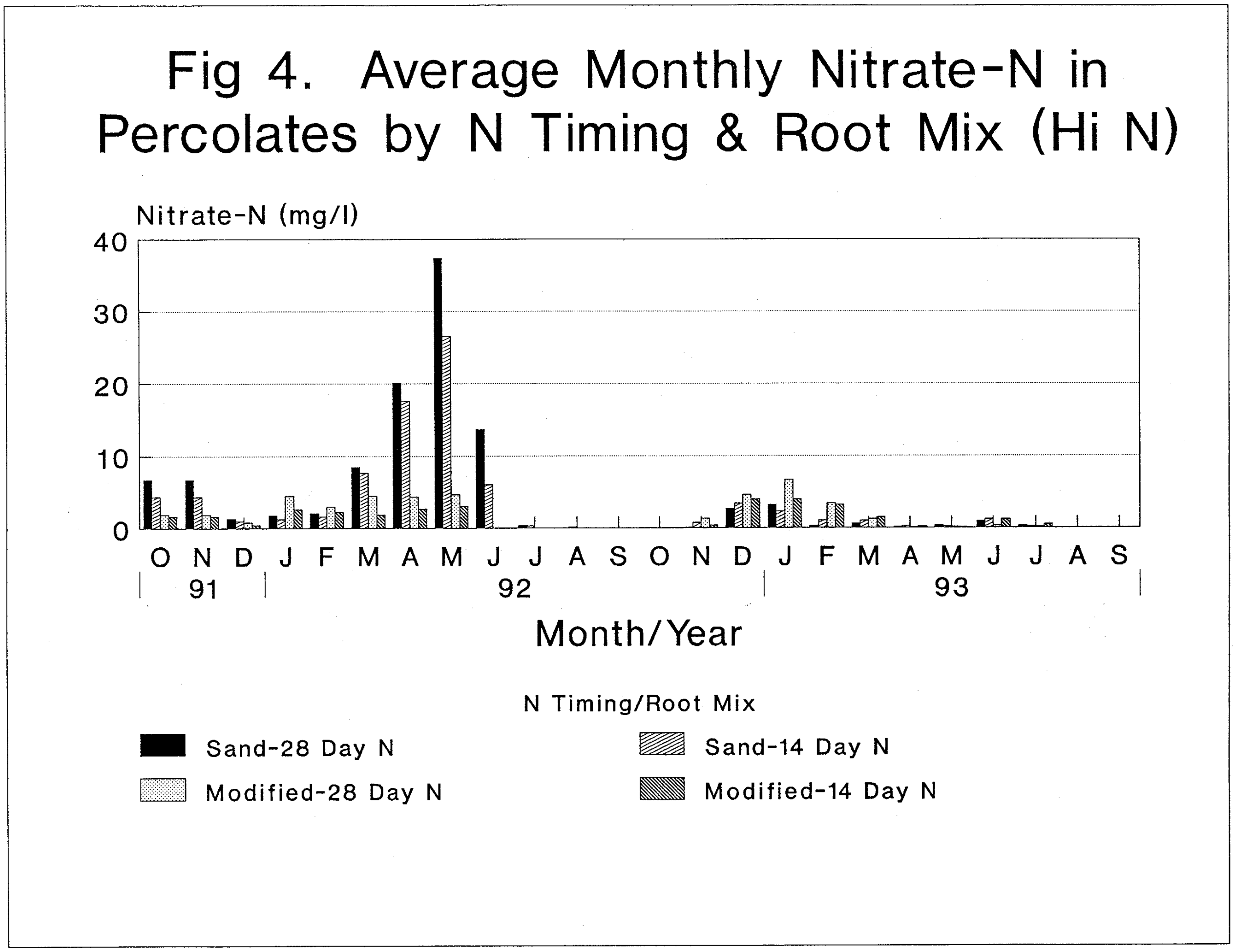

Fig 4. Average Monthly Nitrate-N in Percolates by N Timing & Root Mix (Hi N)
Nitrate-N (mg/l)
40
30
20
10
0
O N D J F M A M J J A S O N D J F M A M J J A S
91
92
93
Month/Year
N Timing/Root Mix
Sand-28 Day N
Sand-14 Day N
Modified-28 Day N
Modified-14 Day N

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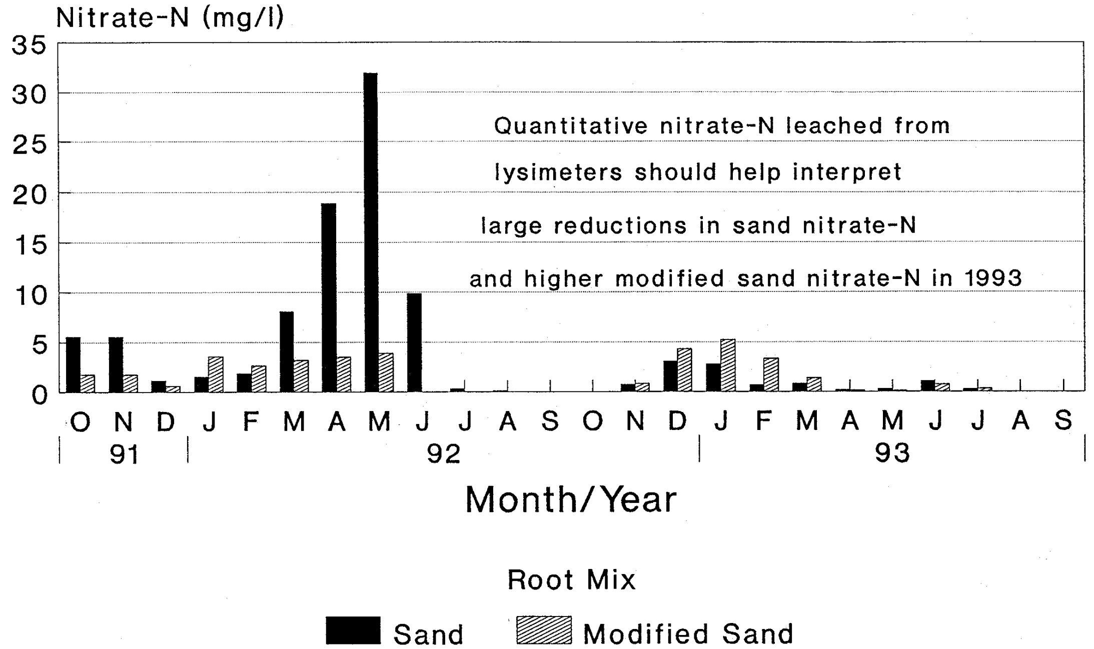
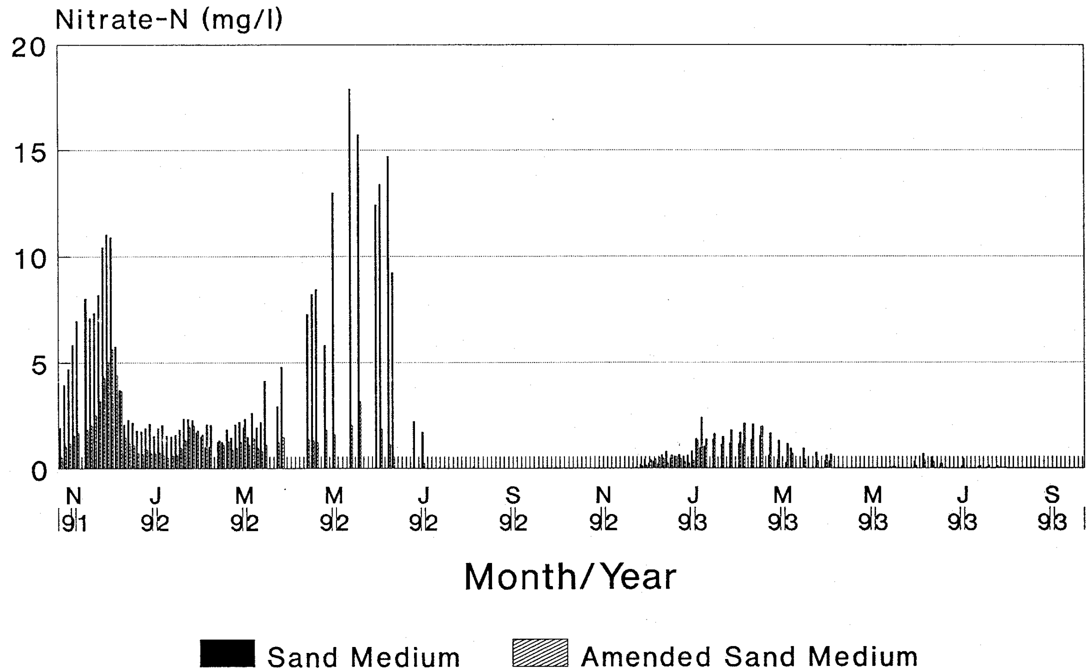
Fig 5. Average Monthly Nitrate-N in Percolates by Root Mix at 586 Kg N/Ha



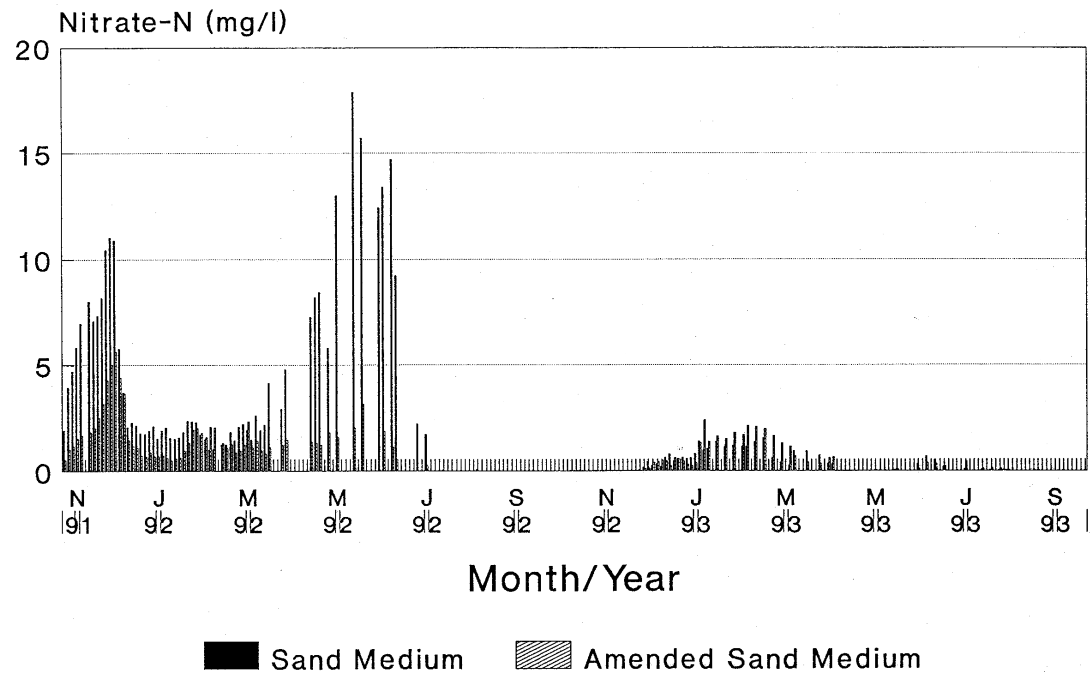
Averaged over Application Timing

Fig 6. Daily Nitrate-N in Sand or Modifid Sand Fertilized with 586 KgN/Ha



Averaged Over Application Timings

Fig 6. Daily Nitrate-N in Sand or Modifid Sand Fertilized with 586 KgN/Ha



Averaged Over Application Timings

00208

International Turfgrass Society Research Journal 7. R.N. Carrow, N.E. Christians, R.C. Shearman (Eds.). Intertec Publishing Corp., Overland Park, Kansas. 1993.

Chapter 79

Comparison of Nitrate Ion Specific Electrode, Segmented Flow Analysis Techniques For Determining Nitrate Levels In Putting Green

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ABSTRACT

Nitrate ion specific electrodes (ISE) are commonly used to determine nitrate-N content in soil water and extracts under field conditions due to their portability, rapidity, and ease of use. Problems exist, however, in determining accurate measurements of nitrate-N at very low or very high levels. Automated colorimetric nitrate-N analysis using cadmium reduction is an Environmental Protection Agency (E. P. A.) approved method for laboratory analysis of nitrate-N in ground and waste waters. An automated version of this test utilizes segmented flow analysis (SFA). A study was done comparing results from these two methods by monitoring differences in nitrate-N content in leachate from sand-based putting greens. The objective was to verify the accuracy of the nitrate ion specific electrode for use in the field by turf professionals as a tool to monitor possible nitrate leachate in areas prone to leaching. Lysimeters were constructed similar to United States Golf Association (USGA) specifications for sand-based putting greens, lined with chlorosulfonated polyethylene reinforced liners, fitted with drainage ports for leachate collection, and seeded to 'Putter' creeping bentgrass (*Agrostis palustris* Huds.). Leachate samples were collected and analyzed for nitrate-N by ISE and by SFA. Correlation between ISE and SFA methods were high ($r \geq 0.93$). Frequent calibration using known samples with similar concentration to those of the leachates provided highly reliable values. The ISE could be used effectively by turf managers in monitoring the impact of fertilization practices in environmentally sensitive areas. The SFA is E. P. A. approved, but not readily available for field use.

INTRODUCTION

A growing concern for eliminating nitrate-N contamination of ground water resources has stimulated monitoring of environmentally sensitive areas where nitrate-N fertilizers are regularly applied. One such area of concern to turf managers is the golf course putting green, where new rootzone construction can consist of 80 to 100% sand. There are several laboratory methods to monitor nitrate-N, including segmented flow analysis (SFA), but the SFA is not available to the average turf professional on a daily basis. One piece of equipment available is the nitrate-N ion specific electrode (ISE). This equipment is relatively inexpensive, portable, easy to operate, and provides rapid results. Measurement range is from 1 to 1400 mg l^{-1} nitrate-N (Mills, 1980). There are certain limitations to the use of an ISE. In highly saline soils the chloride ion can interfere with sample measurement accuracy by up to 10%, depending on the concentration of nitrate present (Orion, 1990). In addition, the use of an ionic strength adjuster (ISA) is necessary. The ISA increases

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background ionic strength to a steady level relative to the level of the nitrate ion (Mills, 1980).

In comparison, the use of SFA to test for nitrate-N in soil leachates requires an investment of many thousands of dollars for the equipment and associated computer software. The device is non-portable and uses an E. P. A. approved method of automated nitrate-N testing (E.P.A., 1984). This method requires the use of precise quantities of several chemicals not available to the average turf manager. In addition, there is extensive training involved in operation of the equipment. For these reasons, SFA is done mostly in laboratories. Results are highly accurate, ranging from 0.7μg l^{-1} to 10.0 mg l^{-1} nitrate, with substantial extension of this range through the use of sample dilution (Berman et al. 1991).

In comparison to these and other laboratory techniques, the use of an ISE by a professional turf manager may be ideal under field conditions. Therefore, a study was conducted to compare ISE and SFA for detecting nitrate-N, with the objective of determining the accuracy of ISE for field use by turf professionals without laboratory resources.

METHODS

CONSTRUCTION. Thirty-six turfgrass lysimeters were constructed similar to USGA putting green specifications with a sand-based rootzone. Each lysimeter was 1.2 by 2.5 m, and lined with a chlorosulfonated polyethylene reinforced liner. A 3.75 mm perforated ABS drain tube was fitted in the bottom of each lysimeter to facilitate collection of leachates in 20-l buckets. Lysimeters were constructed in three blocks of 12, with two rows of six lysimeters in each block. There were 0.2 m between adjacent lysimeters and 1.2 m between each row.

The root zone in each lysimeter was 32 cm deep. Under the root zone was 8 cm of coarse sand followed with 8 cm of pea-sized gravel. The top of the root zone was at ground level. The lysimeter area was seeded to 'Putter' creeping bentgrass (*Agrostis palustris* Huds.) 3 Oct. 1991. Beginning with seasonal rainfall on 25 Oct. 1991, leachate samples were taken daily as necessary until early June 1992. Lysimeters were irrigated under computer control to maintain field capacity. Any leachate collected was the result of naturally occurring rainfall.

As part of a separate study, three different levels of nitrogen fertilizers were applied to the lysimeters. The rates were 195.2, 390.3, and 585.5 kg ha^{-1} yr^{-1}. The nitrogen was supplied as a blend of ammonium sulfate, methylene urea, IBDU, and sulfur-coated urea.

SAMPLE PREPARATION. Samples were collected in 60-ml containers from leachate in each bucket. After collection, samples were prepared for analysis of nitrate-N by either ISE or SFA. Preservatives were added to eliminate conversion from nitrate-N to ammonium-N and to prevent bacterial growth. Different preservation chemicals were used for ISE and SFA as certain ions interfere with both analysis processes. For the ISE, 50-ml samples of leachate were acidified to a pH of 2 by a 1M boric acid solution and stored at 3°C if analysis was not done immediately. For the SFA, 10 ml leachate samples were preserved in 10 ml 2M KCl. The ISE analysis cannot use KCl due to interference caused by the chloride ion (Orion, 1990).

REAGENTS. All solvents were of analytical-reagent grade. The ISE reagents included distilled water, nitrate standards prepared from 0.1M nitrate standard (Orion 920706), and an ionic strength adjuster (ISA) which consisted of 2 ml of 2M

$(NH_4)_2SO_4$ in 100 ml distilled water (Orion ISA 930711). The SFA reagents included 100 mg l^{-1} ammonium nitrate solution for nitrate standards, 1M KCl as sample wash, prepared cadmium coil, color reagent, and ammonium chloride-EDTA solution.

ANALYSES. Samples were analyzed by either the Orion Model 290A pH/ISE meter equipped with a nitrate ion specific electrode and an Orion Model 90-02 double junction reference electrode filled with saturated AgCl (Orion Research Inc., Boston, MA), or by the Alpkem Model 3590 Flow Solution analyzer (Alpkem Corp., Clackamas, OR).

ISE. The ISE analyses were conducted as follows. Samples were removed from 3°C storage and equilibrated at room temperature(≈25°C). Prior to analyses, a standard curve was generated. Standards used for the ISE were 1, 2.5, 5, 7.5, 10, 25, and 50 mg l^{-1} nitrate. Recalibration of the meter during analyses was done with the 1 mg l^{-1} standard. ISA and magnetic stirrers were added to both standards and samples prior to analyses.

Analyses involved placing the sample beaker on a magnetic stirrer stand and inserting the ISE and the reference electrode into the beaker. When readings had stabilized a measurement was taken. Both electrodes were rinsed with distilled water before insertion into the next sample.

SFA. Computer files including nitrate standard values, sample numbering, and sample dilution factors were generated for each sample tray. Nitrate standards were poured into sample cups. Standards used for SFA analysis were 0.5, 1, 1.5, 2, 2.5, 5, and 7.5 mg l^{-1} nitrate. A 1-ml aliquot from each sample vial was pipetted into a sample cup and placed on a 90 cup sample tray along with the nitrate standards. Analyses were initiated at this point, and values for the nitrate standards and samples were outputted to a computer and recorded via accompanying software (SoftPac Plus, Alpkem Corp.).

Following the analyses of 3200 samples taken between 12 Nov. 1991 and 3 Feb. 1992, three 10-day periods were selected at random for comparison of ISE and SFA. The three periods were 12 Nov. 1991 to 21 Nov. 1991, 1 Jan. 1992 to 10 Jan. 1992, and 21 Jan. 1992 to 30 Jan. 1992. Thirty-six samples were taken each day, totaling 360 sample values for each 10-d period. Time periods were compared through linear correlation (MSU-MSTAT).

RESULTS

Results show a high correlation between ISE and SFA, with the lowest $r = 0.93$ and the highest $r = 0.97$.

Fig. 1 shows nitrate values from 12 Nov. 1991 to 21 Nov. 1991. Values for this sample period were higher in nitrate (0 to 30 mg l^{-1}) than the other sample times, perhaps due to fertilizer application prior to sampling and an immature turf stand with very little root system to intercept migrating nitrate. This period generated the highest degree of correlation ($r = 0.97$).

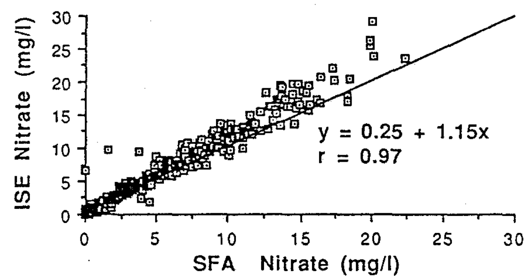

Fig. 1 Relationship between ISE and SFA for nitrate-N analyses from 12 Nov. to 21 Nov. 1991.

Samples taken from 1 Jan. to 10 Jan. 1992 contained lower nitrate levels, ranging from 0 to 7.5 mg l^{-1}, with the majority of the values falling between 0 and 2 mg l^{-1} (Fig. 2). This is due to the time interval between fertilization events and the establishment of the turf and it's root system. The correlation level is lower (r = 0.93) for early Jan. samples than Nov. samples. This occured because a wide range of nitrate standards was used in the electrode analysis when the nitrate levels in the samples were actually quite low.

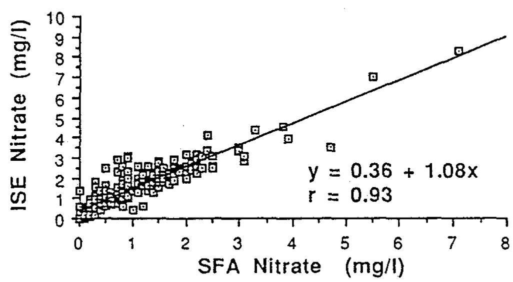

Fig. 2 Relationship between ISE and SFA for nitrate-N from 1 Jan. to 10 Jan. 1992.

The range of nitrate levels for the third sample period was 0 to 18 mg l^{-1}, with the majority of the values occurring in the 0 to 4 mg l^{-1} range (Fig. 3). The degree of correlation was higher for this period because the nitrate standards used in the electrode analysis were limited to 1, 2.5, 5, 7.5, and 10 mg l^{-1}. Omitting the higher standards decreased the range of the standard curve and allowed for more accurate correlation to the SFA values.

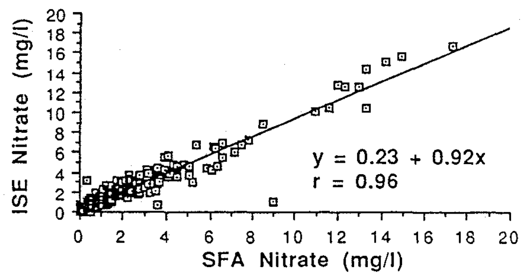

Fig. 3 Relationship between ISE and SFA for nitrate-N from 21 Jan. to 30 Jan. 1992.

CONCLUSION

The results of this study show that there is a high degree of correlation between analyses of nitrate levels in leachate samples from sand-based putting greens by ISE and SFA. Correlation values between methods were never less than $r = 0.93$, and were as high as $r = 0.97$.

The level of correlation observed was directly related to the range of nitrate standards used and the actual nitrate levels in the samples. When the samples contained high levels of nitrate, a wider range of standards gave better correlation between ISE and SFA methods. When sample nitrate levels were low and a wide range of standards was used, a lower degree of correlation was observed.

These results show that if the range of nitrate standards used in ISE analysis is closely matched to actual levels in the samples being analyzed, values can be attained which are comparable to an E. P. A. approved method such as Alpkem's SFA method. Due to ISE's portability, ease and rapid analyses, minimal training period, and low cost compared to SFA, ISE analysis could be used in the field by turf professionals to accurately monitor nitrate levels.

REFERENCES

Berman, R. F., R. N. Curtiss, and S. F. Arment. 1990. Advances in flow analysis instrumentation. *Am. Lab.* 23(18):23-32.

Environmental Protection Agency. 1984. Methods for chemical analysis of water and wastes. 600/4-79-020. Method 353.2.

Michigan State University. 1988. MSTAT-C. Crop and Soil Science, East Lansing, Michigan.

Mills, Harry A. 1980. Nitrogen specific ion electrodes for soil, plant, and water analysis. *Assoc. of Official Anal. Chem.* 63(4):797-801.

Orion Research Incorporated. 1990. Model 93-07 nitrate electrode instruction manual. p. 2-31.