Denitrification Losses from Kentucky Bluegrass Sod

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ABSTRACT

Denitrification may represent an important mechanism in the fate of N applied to turf. Denitrification losses were directly measured from fertilized 'Baron' Kentucky bluegrass (*Poa pratensis* L.) sod samples sealed in acrylic chambers using the acetylene inhibition technique. Losses were correlated with soil texture, percent soil saturation (SAT), and temperature. Losses from turf on a Hadley silt loam soil and Hadley silt soil (both coarse-silty, mixed, nonacid, mesic Typic Udifluvents) incubated at 22°C did not exceed 0.4 and 0.1%, respectively, of the applied potassium nitrate fertilizer (4.5 g N m⁻²) when soil water levels were less than 75% saturated. Soil saturation increased denitrification losses from the silt loam and silt soils to 2.2 and 5.4% of the applied N, respectively. The relationship between percent soil saturation and denitrification loss was quadratic and highly significant for both soils. The equations are: milligrams of N₂O-N m⁻² 10 d⁻¹ = 1432.50 - 38.96 (percent SAT silt soil) + 0.26 (percent silt soil)² or 130.80 - 5.40 (percent SAT silt loam soil) + 0.05 (SAT silt loam soil)². A linear relationship [milligrams of N₂O m⁻² 10 d⁻¹ = 0.49(°C) - 9.70] existed between denitrification losses and soil temperatures between 22 and 30°C in the silt soil at 75% of soil saturation. Soil temperatures of 30°C or greater coupled with saturated soil conditions resulted in the greatest losses, equivalent to 44.6 and 92.6% of the applied N to the silt loam and silt soils, respectively. Denitrification losses did not increase at soil temperatures above 30°C. These results indicate that denitrification loss from fertilizers applied to turfgrasses may not be a serious problem unless the soils are saturated and at higher soil temperatures.

Additional index words: Nitrous oxide, Nitrogen fertilizer, *Poa pratensis* L., Turfgrass.

DENITRIFICATION loss after N fertilizer applications to field and vegetable crops (1,5,15,20) and grasslands (4,5,7,12,14,21) has been studied extensively. No research data is available concerning denitrification losses from highly managed turfgrass areas.

Conditions that may promote denitrification losses include light, frequent irrigations (4,5,12,14), fertilizer N applications (4,14,21), incorporation of organic matter into soils (4,12), and higher soil temperatures (4,7,10). These conditions are found in high-quality turfgrass areas, with the organic matter being contributed by the turfgrass root system. Soil temperatures under closely mowed turf may be high (2).

Denitrification losses from irrigated vegetable crops can be as high as 233 kg N ha⁻¹ yr⁻¹ (52% of applied N) (14,15). Losses from small grains range from 1 to 19 kg N ha⁻¹ yr⁻¹ (1,5,20). Perennial ryegrass (*Lolium*

perenne L.) swards may lose from 1 to 29 kg N ha⁻¹ yr⁻¹ (12,14). Losses from the grasses are small despite N applications as high as 500 kg N ha⁻¹ yr⁻¹ (14). Although peak effluxes from soils under grasses and other crops may be similar in magnitude, the duration is shorter in the presence of grasses due to the grass root system's ability to quickly deplete soil NO₃-N levels (14). Turfgrass root systems can be shallow due to light, frequent irrigation and close mowing.

Peak N₂O-N effluxes (20-50 mg N m⁻² d⁻¹) tend to occur during the first few days after an irrigation or rainfall event (6,17,18). These effluxes are associated with wetter soil conditions (more than 20% w/w) and higher NO₃-N levels (more than 5 µg N per gram of soil) (14). These losses are short lived but can be significant in terms of their contribution to total annual denitrification loss.

Soil water and texture influence the denitrification process by affecting gas exchange and the diffusion of O₂ to active microbial sites (12,17,21). Small, frequent irrigations have been found to stimulate denitrification (6,7,18), while larger, more frequent irrigations may not (16). A small water input into a finer textured soil may result in greater denitrification losses than from coarser textured soils (18,21).

Increased soil temperature increases denitrification rates (3,4,10). Many factors, however, influence the quantitative effects of temperature on denitrification rate. These include diversity and availability of soil organic matter, and the selective effects of temperature on different bacterial species and denitrifying populations (8,9). Bremner and Shaw (3) found that maximum soil denitrification rates occurred in vitro at 30°C in six soils amended with glucose and NO₃-N.

The objectives of this study were to determine total denitrification losses from Kentucky bluegrass sod as influenced by soil texture, soil water content (percent saturation), and soil temperature.

MATERIALS AND METHODS

'Baron' Kentucky bluegrass sod samples (30.5 by 30.5 by 7.5 cm) from Hadley silt and Hadley silt loam sites (Table 1) were installed into clear acrylic chambers constructed of 1.3-cm-thick clear acrylic, and had internal dimensions of 30.5 by 30.5 by 13.0 cm. Each chamber was airtight when its lid was sealed on using a lithium paste. Five perforated copper tubes were installed into the bottom of each chamber, which permitted the injection of acetylene (C₂H₂) into the sod soils through a septum-sealed sidearm that extended through the chamber wall. The first and second experiments described in this study were conducted in a growth room while the third experiment was done in growth chambers.

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Effect of Soil Water Content

The initial soil water content of the silt soil was 91.7% of soil saturation (48.4% water, w/w). Soil water levels were determined gravimetrically. Six sod samples were allowed to air dry until the soil was approximately 50% saturated. Reagent grade potassium nitrate (KNO_3 , 3.02 g per sample) was dissolved in 1.5 L of water and applied to each of two samples. Final soil water content of these samples was 100% of saturation. Six hundred milliliters of water were used to apply the same amount of KNO_3 to two more samples, bringing the soil water contents to approximately 75% of saturation. The remaining two samples were allowed to dry to a soil water content of 37% of saturation before 400 mL of water containing KNO_3 was applied, yielding a final soil water content of approximately 50% of soil saturation.

Following N fertilizer and water applications, the chamber lids were sealed onto each chamber. One hundred milliliters of C_2H_2 were injected into each box, giving a final soil C_2H_2 concentration of approximately 1% (v/v). The chambers remained sealed for 12 h before headspace gas samples were removed. The chambers were then opened and fresh air was circulated around the sod and through the thatch using a hand-held vacuum cleaner. The chambers were again sealed, injected with C_2H_2 , and allowed to stand for another 12 h. This process was repeated for 10 d, with 12-h intervals corresponding to light (19.1 W m^{-2})/dark periods. Soil temperature was maintained at 22°C .

After sampling, the headspace gas was analyzed for N_2O -N content using a Varian Series 2700 moduline gas chromatograph (Varian Associates, Inc., Palo Alto, CA) equipped with an electron capture detector (Ti^{3+}H). Nitrous oxide was separated from other gases using a Varian Porapak Q column (80/100 mesh, 2 m by 3.2 mm). Column temperature was 75°C , injector port temperature was 195°C , and detector temperature was 220°C . The carrier gas was N_2 at a flow rate of 14 mL min^{-1} . By utilizing the acetylene-inhibition technique, N_2O -N loss represented total denitrification loss (16).

After 10 d the sod samples were replaced with six fresh samples from the silt soil site. Three additional samples were also used for a total of nine sod samples. Initial soil water content of the sod was 66% of soil saturation. Potassium nitrate was applied in quantities of water ranging from 400 mL to 2 L, with treatments varying by 200-mL increments. Final soil water contents ranged from 72 to 106% of soil saturation.

The above study was repeated with nine sod samples from the silt loam soil site (Table 1). Initial soil water content was 93.5% of saturation (40% water, w/w). After soil water levels fell to approximately 68% of soil saturation, seven sod samples received KNO_3 (3.02 g per sample) applied in water quantities ranging from 400 to 900 mL. The two remaining sod samples were dried to 45% of soil saturation and the fertilizer was applied in 500 mL of water. Final soil water levels ranged from 33 to 101% of soil saturation. Soil temperature was maintained at 22°C .

Total denitrification loss was calculated on a daily basis as well as on a 10-d basis. Within each soil type, a stepwise regression analysis was used to test for a significant relationship between total denitrification loss from KNO_3 -N treated sod samples and the level of soil saturation. Controls were not used during this study. Preliminary results had shown that total denitrification loss from nonfertilized sod incubated at 22°C was insignificantly low, and often undetectable, even under saturated soil conditions.

Effect of Temperature

In this study, six sod samples from the silt soil were installed in the acrylic chambers and incubated at 22°C . Initial soil water content was 66% of soil saturation. Potassium

Table 1. Characteristics of Hadley silt and Hadley silt loam.

	Soil type	
	Silt	Silt loam
Particle size, %		
Clay	6	4
Silt	83	79
Sand	11	17
Organic matter, %	5.0	3.9
Infiltration rate, cm h^{-1}	10.9	6.9
Percent of soil saturation at field capacity	56.8	51.8
pH	6.35	5.79

nitrate (3.02 g per sample) was applied to three sod samples in 600 mL of water while three controls received water only. Controls were used in this study because preliminary work had not been conducted to determine N_2O -N losses from unfertilized sod incubated at higher temperatures. Final soil water content was approximately 75% of soil saturation. Total denitrification loss was calculated for a 10-d period. The study was repeated at 26 and 30°C , and a linear regression analysis was used to determine the relationship between denitrification losses and soil temperature.

Interaction of Soil Water Content and Temperature

Eight sod samples were collected from the silt loam soil site and installed in the acrylic chambers. Initial soil water content was 87% of soil saturation. All samples were completely saturated with 2 L of water, with four samples receiving KNO_3 . Two fertilized and two unfertilized samples were incubated at a soil temperature of 30°C , and the remaining four samples were incubated at 35°C for 10 d. This experiment was repeated using sod from the silt soil site. Initial soil water content of sod from the silt soil was 79% of soil saturation.

An analysis of variance was used to test for significant differences between total denitrification losses within each soil.

Denitrification losses from controls, when observed, were subtracted from the losses of the KNO_3 -N treated sod in order to calculate fertilizer-N loss through the denitrification process.

RESULTS AND DISCUSSION

Effect of Soil Water Content

Soil water content had a significant quadratic influence on denitrification loss from sod on both the silt and silt loam soils (Table 2). Total denitrification losses were low when both soils were less than 80% saturated (Fig. 1) and represented less than 0.1 and 0.4% of the 4.5 g N m^{-2} applied to the silt and silt loam soils, respectively. Regardless of soil type, preliminary results found that no detectable N_2O -N losses occurred from unfertilized controls at soil water contents below 80% soil saturation, while less than $4 \text{ mg N m}^{-2} 10 \text{ d}^{-1}$ were lost at 98% of soil saturation.

Table 2. Regression of percent soil saturation on total denitrification losses ($\text{mg N}_2\text{O-N m}^{-2} 10 \text{ d}^{-1}$) from Kentucky bluegrass sod after $\text{NO}_3\text{-N}$ addition (4.5 g N m^{-2}).

Soil type	Dependent variable	Independent variable†	R^2	F-test
Silt	$\text{mg N}_2\text{O-N m}^{-2} 10 \text{ d}^{-1} = 1432.50 - 38.96(\text{SAT}) + 0.26(\text{SAT}^2)$		0.94	**
Silt loam	$\text{mg N}_2\text{O-N m}^{-2} 10 \text{ d}^{-1} = 130.80 - 5.40(\text{SAT}) + 0.05(\text{SAT}^2)$		0.97	**

** Regression equation significant at the 0.01 probability level.

† SAT = percent soil saturation.

Fig. 1. The influence of soil water content on total denitrification losses from Kentucky bluegrass sod on two soil types incubated at 22°C following KNO_3 addition (4.5 g N m^{-2}).

Fig. 2. $\text{N}_2\text{O-N}$ efflux from Kentucky bluegrass sod at 22°C (d/n) at various soil water levels (percent saturation) following KNO_3 addition (4.5 g N m^{-2}). Note differences in scale.

Table 3. Total denitrification losses from Kentucky bluegrass sod on a silt soil (75% saturated) incubated at three soil temperatures after $\text{NO}_3\text{-N}$ addition (4.5 g N m^{-2}).

Soil temperature, °C	mg $\text{N}_2\text{O-N m}^{-2} 10 \text{ d}^{-1}$ †	Percent applied N lost
22	0.98 ± 0.17 ‡	0.02
26	2.93 ± 0.39	0.07
30	4.98 ± 0.51	0.11

† mg $\text{N}_2\text{O-N m}^{-2} 10 \text{ d}^{-1} = 0.49 (^\circ\text{C}) - 9.70$; $r^2 = 0.99^{**}$ ($P = 0.01$).‡ Mean of three replications $\pm$ standard error.

Denitrification losses increased when soil water levels were greater than 80% of saturation (Fig. 1). Maximum losses occurred at saturation and accounted for approximately 5.4 and 2.2% of N applied to the silt and silt loam, respectively. These losses are within the range (0.1–6.6% of applied N) observed by other researchers working with permanent forage grass swards (12,14). Smith and Tiedje (19) also found denitrifying activity to be greatly increased at soil water levels greater than 75% of saturation.

Soil texture can influence the extent of denitrification since water movement through a finer textured soil may be impeded resulting in temporary anaerobic soil conditions (21). Sextone et al. (17) reported that greater denitrification losses occurred from a clay loam soil than from a sandy loam soil. Similar results were shown in our study; however, because of the design of the acrylic turf chambers, water drainage was not possible from sod samples. Therefore, the difference in soil water content as affected by a soil's ability to drain was not a variable in this study as it would be in field studies. In addition, soil $\text{NO}_3\text{-N}$ content was similar (50–70 $\mu\text{g N}$ per gram of soil) for both soils at the time of the completion of the study. Therefore, the larger denitrification losses associated with the silt soil may have been due in part to other soil properties, including pH and percent organic matter content (Table 1), as well as the silt soil's ability to support larger denitrifying populations (11).

Table 4. Total denitrification losses from Kentucky bluegrass sod on two soil types at 100% soil saturation and incubated at high soil temperatures after $\text{NO}_3\text{-N}$ addition (4.5 g N m^{-2}).

Soil type	Soil temperature, °C	mg $\text{N}_2\text{O-N m}^{-2} 10 \text{ d}^{-1}$	Percent applied N lost	F-test
Silt	30	4217 ± 10 †	94	NS‡
	35	4102 ± 32	91	
Silt loam	30	2037 ± 13	46	NS
	35	1866 ± 13	41	

† Mean of three replications $\pm$ standard error.

‡ NS = nonsignificant at the 0.05 probability level.

Large but short-lived $\text{N}_2\text{O-N}$ emissions have been observed by other researchers (6,14,17,18), with peak emissions as high as 50 and 90 $\text{mg N m}^{-2} \text{ d}^{-1}$ from perennial ryegrass swards. In our study, peak emissions were as high as 48 and 60 $\text{mg N m}^{-2} \text{ d}^{-1}$ for the silt loam and silt soils, respectively (Fig. 2). In general, longer periods of $\text{N}_2\text{O-N}$ efflux occurred at soil water levels equal to or greater than 80% of soil saturation, particularly in the silt soil.

Effect of Temperature

Soil water levels below 80% of saturation resulted in denitrification losses that did not vary much as a result of small differences in water content (Fig. 1). As such, a soil water content of approximately 75% of saturation was selected to examine the influence of soil temperature on denitrification losses. The silt soil was also selected because of its larger denitrification potential, as indicated by total denitrification losses under saturated soil conditions (Fig. 1) and large denitrifier populations (11). The magnitude of $\text{N}_2\text{O-N}$ efflux increased as soil temperature increased from 22 to 30°C (Table 3). Total denitrification losses were linearly related (milligrams of $\text{N}_2\text{O-N m}^{-2} 10 \text{ d}^{-1} = 0.49(^\circ\text{C}) - 9.70$) to soil temperature. The loss observed from the sod at 22°C was in close agreement with the losses observed in the previous study where the silt soil was

Figure 3. $\text{N}_2\text{O-N}$ efflux from Kentucky bluegrass sod on a saturated silt soil incubated at high soil temperatures following KNO_3 addition (4.5 g N m^{-2}). Vertical lines represent standard error.

Figure 4. N_2O -N efflux from Kentucky bluegrass sod on a saturated silt loam soil incubated at high soil temperatures following KNO_3 addition (4.5 g N m^{-2}). Vertical lines represent standard error.

maintained under similar conditions (Fig. 1). These losses represented less than 0.1% of the N fertilizer applied.

Interaction of Soil Water Content and Temperature

The interaction of increased soil temperatures and saturation resulted in comparatively large denitrification losses from both soils (Table 4). These losses were equivalent to approximately 44.6 and 92.6% of N applied to the silt loam and silt soils, respectively.

Greater denitrification losses did not result by increasing the soil temperature from 30 to 35°C, which may indicate that a maximum denitrification rate occurred at approximately 30°C. This agrees with the work of Bremner and Shaw (3). Ryden (14) found the largest denitrification losses to occur from a perennial ryegrass sward when soil water levels and temperatures increased in the upper 2.5 cm of soil. This has also been observed by others working with forage grass swards (4,13).

Saturated turf soil conditions and increased soil temperatures resulted in denitrification losses that were much higher than losses reported by others working with perennial forage grasses (13,14). Peak N_2O -N emissions of $2100 \text{ mg N}_2\text{O-N m}^{-2}$ (Fig. 3) and $750 \text{ mg N}_2\text{O-N m}^{-2}$ (Fig. 4) from both turf soils are also considered to be extremely high in comparison to peak N_2O -N emissions from other fertilized grass swards (4). Ryden (15) did, however, observe a peak flux of 3360 mg N m^{-2} from irrigated vegetables.

The results presented in this study represent the first effort to directly measure denitrification losses from N fertilized turf. In a previous report, we have shown that relatively large populations of denitrifying microorganisms exist in turfgrass soils, indicating a high potential for denitrification (11). Denitrification losses from these turf soils, however, were as low as in other cropped soils, until soil water levels approached saturation. Saturated soil conditions in combination with

elevated soil temperatures resulted in very large denitrification losses from fertilized turf. These conditions, in general, do not persist for long periods of time in the field, but this and other research has shown that large denitrification losses may occur quickly and in relatively short time periods.

ACKNOWLEDGMENTS

Financial support for this research has come from the Department of Plant and Soil Sciences through funding for Experiment Station Project 526 and the O. J. Noer Turf Research Foundation.

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