**Nitrous oxide production from soils amended with fall-applied hog manure**

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## Introduction

Hog production in the prairie provinces has doubled in the last decade and there is a continuing move from small, family owned hog farms (20-30 sows) to much larger (>600 sows) commercial hog operations (CSALE, 1996). Along with this increase in production comes an inevitable increase in manure volumes and the accompanying issue of its disposal. The strategy adopted by much of the agricultural community in Saskatchewan has been to inject manure into agricultural fields as an organic fertilizer/soil amendment. Hog manure can supply much of the N and P needed for crop production (Kaminiski and Kaminiski, 1993) and, in some soils, can yield significant benefits in regards to particle aggregation and soil tilth (Larney et al., 1991). Sub-surface injection of manure is intended to minimize ammonia losses and odors associated with manure. However, because of the very nature of liquid hog manure this system may actually increase the potential for denitrification (i.e., the microbially mediated reduction of $NO_3^-$ to $N_2$). In turn, this may result in increased production and release to the atmosphere of nitrous oxide ($N_2O$; a gaseous intermediate formed during the denitrification process).

It is currently estimated that agricultural activity accounts for as much as 80% of all the anthropogenic $N_2O$ entering the atmosphere (Beauchamp, 1997). Moreover, $N_2O$ accounts for about 40% of all greenhouse gas emissions resulting from agricultural activity and animal manures have been identified as important sources of this $N_2O$. Manure applications produce increases in both microbial numbers and activity. In turn, these larger, more active microbial communities consume more oxygen which can result in the creation of anaerobic zones in the soil. Sub-surface injections of liquid swine manure may further exacerbate the situation; i.e., because $O_2$ diffusion is substantially slower through water than through air, its movement into the soil will be significantly reduced under the saturated or near-saturated conditions that result from the application of liquid manures. The microbial conversion of $NO_3$ to $N_2O$ in the soil depends on the existence of specific conditions; i.e., an $O_2$ depleted (anaerobic) environment and adequate supplies of both readily available organic-C and substrate-N ($NO_3$-N). Injection of large volumes of water (up to 12,000 gal per acre) associated with the hog manure causes fairly extensive (though transient) zones of anaerobiosis to occur in the soil while the manure itself provides both the N and C needed by denitrifying bacteria. Furthermore, because denitrification is a microbial process, increases in denitrification are accompanied by increased microbial respiration and hence, the production of a second greenhouse gas – carbon dioxide ($CO_2$).

The objective of this research is to compare $N_2O$ emissions and potential denitrification activity from agricultural plots amended with hog manure to plots fertilized with equivalent rates of commercial urea fertilizer.

## Materials and methods

The research was carried out on plots located in the Black soil zone near Humboldt, SK. The experimental design is a randomized complete block design with eight treatments replicated four times. The treatments are: (i) the check (no manure or urea fertilizer); (ii-iv) swine manure applications equivalent to 50, 100, and 200 lbs available N per acre - applied using a low disturbance coulter injector system; (v) broadcast application of swine manure at a rate equivalent to 50 lbs available N per acre; and (vi-viii) side-banded urea applications equivalent to 50, 100, and 200 lbs available N per acre. Nitrous oxide and $CO_2$ emissions and denitrification activity were monitored eight times between April and November 1998: before field preparation and seeding, after seeding, 24-h following rainfall events totaling ≥ 5-mm (three times), once during a prolonged period of no precipitation, prior to fall manure application, and as soon after manure application as was practical. Ambient $N_2O$ evolution was measured directly in the field using the 'sealed chamber' method (Corre et al., 1996). Gas samples were collected from the chambers, stored in exotainers under positive pressure, returned to the lab and analyzed by gas chromatography for $N_2O$ and $CO_2$ (Hynes et al., 1985). Denitrification potential was measured in the lab using the acetylene-blockage technique (Yoshinari et al., 1977). In addition, on each sampling date, volumetric soil water content, $NH_4^+$ and $NO_3^-$ concentrations and water soluble organic C were determined in triplicate for each of the 32 sampling points using standard methods.

## Results and discussion

In general, both ambient $N_2O$ fluxes and potential denitrification activity increased with the rate of application of both manure and urea (Fig. 1). However, in both cases $N_2O$ fluxes were higher from the manure-amended plots compared to the urea fertilized plots. Not unexpectedly, field measurements of ambient $N_2O$ fluxes (Fig. 1A) were substantially lower than those associated with potential denitrification activity (Fig. 1B). For example, on the October 22 sampling date (10 days after the fall manure application), plots receiving 200 lbs manure-N/acre yielded a median value of 0.08 g $N_2O$-N $ha^{-1}$ $d^{-1}$ compared to about 1000 g $N_2O$-N $ha^{-1}$ $d^{-1}$ in potential denitrification activity. Both the occurrence and magnitude of the $N_2O$ emissions exhibited considerable variation throughout the sampling season and were largely dependent on the amount of precipitation received just prior to sampling.

Because of the highly skewed nature of the $N_2O$ data, statistical analyses were performed using nonparametric methods (Table 1). Analysis of variance verified that $N_2O$ emissions and denitrification activity were greatest from plots receiving the 200 lbs N/acre manure application. In addition, both fluxes were different from the check and the equivalent urea application.

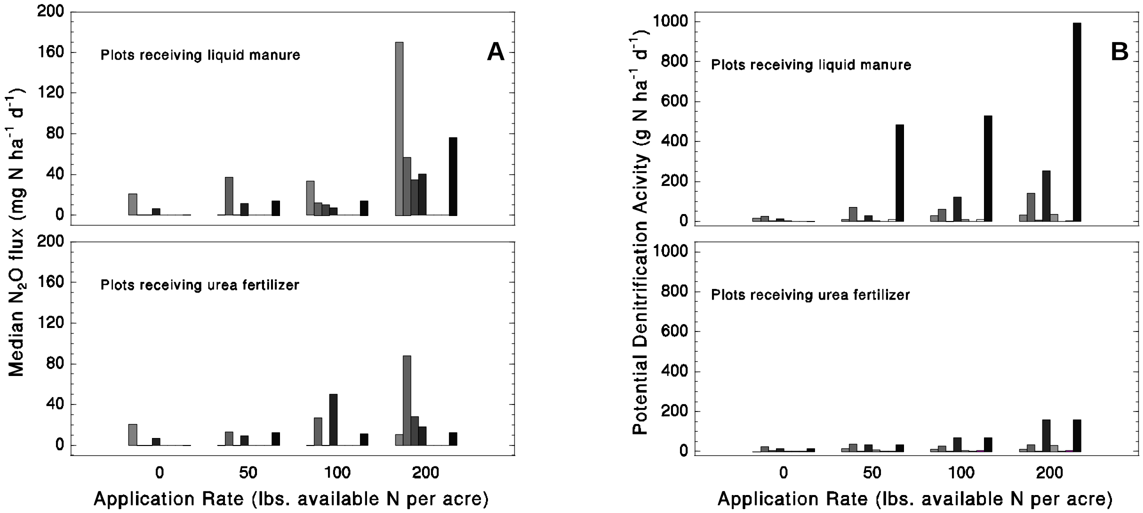


*Figure 1. Nitrous oxide ($N_2O$) fluxes measured during the 1998 field season. [A] ambient levels of $N_2O$; [B] potential denitrification activity. Sampling dates (from left to right): April 28, May 20, June, June 22, July 9, July 30, October 1, and October 22.*

Table 1. Statistical comparisons of ambient $N_2O$ fluxes and denitrification activity in soils amended with liquid hog manure and urea.

| | | | - - - - - - - - Ambient $N_2O$ Flux - - - - - - - - | | |
|---|---|---|---|---|---|
| Treatment[1] | Check | 50M-Br | 50M-I | 100M-I | 200M-I |
| 50M-Br | NS[2] | | | | |
| 50M-I | NS | NS | | | |
| 100M-I | NS | NS | NS | | |
| 200M-I | * | * | * | * | |
| 50U-Bn | NS | NS | NS | | |
| 100U-Bn | NS | | | NS | |
| 200U-Bn | NS | | | | NS |
| | | | - - - - Potential Denitrification Activity - - - - | | |
| | Check | 50M-Br | 50M-I | 100M-I | 200M-I |
| 50M-Br | NS | | | | |
| 50M-I | NS | NS | | | |
| 100M-I | * | NS | NS | | |
| 200M-I | * | * | NS | NS | |
| 50U-Bn | NS | NS | NS | | |
| 100U-Bn | NS | | | NS | |
| 200U-Bn | NS | | | | * |

[1] Treatments are coded by application rate (50, 100, or 200 lbs available N $acre^{-1}$); fertilizer source (manure = M, urea = U); and application method (broadcast = Br, subsurface injection = I, banding = Bn).

[2] Only meaningful comparisons are shown. NS = not statistically significant;
***** = significant difference ($\alpha$= 0.10).

In general, ambient $N_2O$ emissions were highly correlated with volumetric water content, $NH_4^+$ concentration, and potential denitrification activity. There also was a weak correlation between ambient $N_2O$ flux and the concentration of $NO_3$-N in the soil. These results indicate that $N_2O$ fluxes from the manure-amended plots reflect microbial nitrification of the organic and inorganic N in the manure as well as denitrification.

Differences in both ambient $N_2O$ flux and potential denitrification activity between the manure and urea amended plots were particularly striking during the spring (after the soil temperature had begun to rise) and shortly after fall application of the manure and urea (Fig. 1). These differences are believed to reflect differences in the availability of both $NO_3$ and soluble organic C under the different treatments. Fall application of manure supplies soluble organic C and inorganic N that, because of cold winter temperatures, persists into the spring. Warmer spring and summer temperatures activate microbial populations that utilize the C and N throughout the growing season. In addition, denitrification is often greatest in shallow subsurface soil layers (Rice and Rogers, 1993) and much of the $N_2O$ thus generated may remain dissolved in the soil water (Amundson and Davidson, 1990). Because field measurements of $N_2O$ flux usually involve only gas fluxes at the soil surface, a considerable amount of the $N_2O$ produced via denitrification may go undetected when using a sealed chamber method to quantify these fluxes. A recent report by Chang et al. (1998) demonstrated that significant amounts of $N_2O$ can be transpired through a crop. Consequently, because the manure amended plots exhibit significantly higher rates of potential denitrification activity than realized $N_2O$ flux from the soil surface, there may be considerably more subsurface $N_2O$ available for release to the atmosphere. If this is indeed the case, movement through the transpiration stream represents a very plausible avenue for the transfer of this $N_2O$ to the atmosphere. By the end of summer very little difference in soluble organic C and $NO_3$ exists between the manure and urea amended plots and hence, little difference in ambient $N_2O$ flux and potential denitrification activity occur.

Nitrous oxide fluxes and potential denitrification activity represent only one pathway for gaseous N losses from the urea and manure amended systems. Nitrogen in urea fertilizer also is subject to a number of losses, particularly at the time of application. Significant amounts of ammonia escape to the atmosphere from both urea and manure during application although the magnitude of the losses between the two amendments is not known. It is possible that the higher fluxes of $N_2O$ from the manure amended soils are balanced by ammonia loss from urea amended soils at the time of application. However, with the limited data available, it is not yet possible to compare quantities or patterns of loss between the two systems.

**Summary**

Sub-surface injection of manure into agricultural plots generally increased the potential denitrification activity compared to the equivalent application rate of commercial urea fertilizer. Overall, the higher the rate of manure application, the higher the denitrification potential. Not unexpectedly, the highest potential denitrification activity occurred shortly after the fall application of manure.

Field measurements of $N_2O$ fluxes were substantially lower than potential denitrification activity. However, the pattern of $N_2O$ emissions tended to mirror those for potential denitrification activity, in that the highest fluxes were always associated with the highest application rate. The fall manure application resulted in much larger increases in denitrification potential than actual $N_2O$ emitted. Ambient $N_2O$ emissions were highly correlated with volumetric water content, $NH_4^+$ concentration, and potential denitrification activity.

Future research will expand the scope of the study to include hog manure amendments in the Brown and Dark Brown soil zones and monitoring $N_2O$ fluxes through overlying crops.

**References**


Amundson, R.G. and Davidson, E.A. 1990. Carbon dioxide and nitrogenous gases in the soil environment. J. Geochem. Explor. 83:13-41

Beauchamp, E.G. 1997. Nitrous oxide emission from agricultural soils. Can. J. Soil Sci. 77:113-123.

Centre for Studies in Agriculture, Law and the Environment. 1996. Expanding intensive hog operations in Saskatchewan: Environmental and legal constraints. CSALE Occasional Paper #3.

Chang, C., Janzen, H.H., Cho, C.M. and. Nakonechny E.M. 1998. Nitrous oxide emission through plants. Soil Sci. Soc. Am. J. 62:35-38.

Corre, M.D., van Kessel, C. and Pennock, D.J. 1996. Landscape and seasonal patterns of nitrous oxide emissions in a semiarid region. Soil Sci. Soc. Am. J. 60:1806-1815.

Hynes, R.K., Ding, A.L. and Nelson, L.M. 1985. Denitrification by Rhizobium fredii. FEMS Microbiol. Lett. 30:183-186.

Kaminiski, D., and T. Kaminiski. 1993. Producer experience with feedlot manure. *In* Proceedings and Recommendations, Manure Management Workshop, Saskatoon, SK, Sask. Ag. and Food Extension Service.

Larney, F.J., C. Chang, and B.S. Freeze. 1991. Manure Application Under Dryland and Irrigated Conditions. Research Station, Agriculture Canada, Lethbridge Alberta; Powlson, D.S. 1993.

Rice, C.W. and Rogers, K.L. 1993. Denitrification in subsurface environments: Potential source for atmospheric nitrous oxide. Pages 121-132 *in* D.E. Rolston, ed. Agricultural ecosystem effects on trace gases and global climate change. ASA Spec. Publ. 55,ASA, CSSA, and SSSA Madison, WI.

Yoshinari, T., Hynes, R. and Knowles. R. 1977. Acetylene inhibition of nitrous oxide reduction and measurement of denitrification and nitrogen fixation in soil. Soil Biol. Biochem. 9:177-183.