SEASONAL FLUCTUATIONS OF N_2O EMISSION IN DIFFERENT SOIL LANDSCAPE SYSTEMS

M. D. Corre D. J. Pennock and C. van Kessel Department of Soil Science, University of Saskatchewan, Saskatoon.

ABSTRACT

Nitrous oxide has been widely recognized as a major scientific and environmental 'issue because of its involvement in global warming and destruction of the atmospheric ozone layer. The inherently high temporal and spatial variabilities of N_2O emission has hindered attempts to establish predictive relationships with its controlling variables. Hence achieving annual estimates for N_2O emission at a large scale continues to pose a challenge for researchers.

As a pre-requisite to quantify annual N_2O emissions at a regional scale, this study was conducted to determine the landscape- and seasonal-scale patterns of N_2O emission. Nitrous oxide emissions were assessed in six soil landscape systems chosen as representative units of a delineated region in the Black soil zone. The region is stratified into three main textural groups, within which different land uses were selected: clay loam (fertilized wheat and pasture sites), fine sandy loam (fertilized canola site), and sandy (fertilized oat, alfalfa, and forest sites). A systematic grid design was employed at each site and N_2O emission was monitored using a sealed chamber method.

A clear landscape-scale pattern of N_2O emission was observed; lower landscape positions showed higher N_2O flux than the upper landscape positions. This pattern remained consistent throughout the season, with N_2O fluxes increasing towards the early summer, decreasing towards the late summer, and virtually ceasing by the onset of frost (fall). A considerable pulse of activity was also observed during the early spring (March and April). This indicates the importance of an appropriate temporal sampling scheme that would account for this spring activity in order to achieve a more reliable annual estimate of N_2O emission. In any model used for large-scale and long-term estimates of flux, it is therefore necessary to reflect not only the landscape variability but also the seasonal variability of N_2O emission.

INTRODUCTION

Soils generally act as a source of N_2O (Mosier *et al.*, 1981; Seiler and Condrad, 198 1). Of the biotic an dabiotic processes involved in the production of N_2O in the soil, the bacterial processes o fnitrification and denitrification are clearly dominant (Hutchinson and Davidson, 1993; Mosie r*et al.*, 1983). Although the physiology and biochemistry o fnitrification and denitrification are relatively well elucidated in laboratory studies, the interactions of multiple physical, chemical and biological factors complicate the regulating factors of these processes in nature. The complex interactions between factors results in high spatial and temporal variations of N_2O emission, and makes i tdifficult to establish a predictive relationship between its controlling variables.

Groffman (1991) pointed out that increasing the scale of investigation in both time (seasonal rather than daily) and space (landscape-scale rather than field-scale) appeared to be useful in overcoming the variability problems. Recent studies in Saskatchewan used a quantitative classification of slope form to define the sampling units (landform elements) in assessing N20 emission from denitrification at the landscape-scale (Pennock *et al.*, 1992; Van Kessel *et al.*, 1993). This spatial sampling scheme accounted for the variation of soil characteristics and moisture redistribution in the landscape, which are important ecological controls of N_2O emissions. Van Kessel *et al*. (1993) also noted that because the dominant controlling factor of N20 emission may vary during the season, it is essential that any spatially-based model used to estimate annual N_2O flux should reflect the seasonal variation of N20 emission activity. Knowledge of the spatial and temporal variabilities at landscape- and seasonal-scales is important not only for quantifying N20 emission but also for developing site-specific management strategies. This study was conducted to determine the factors, and the landscape- and seasonal-scale patterns of N20 emission under different soil landscape systems.

METHODOLOGY

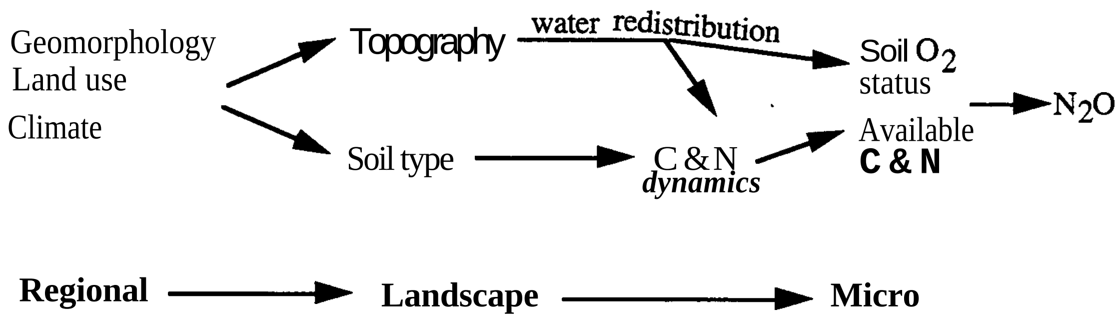
This study is part of a project aimed at estimating annual N20 flux at a regional scale. A region was selected in the Black soil zone near St. Louis, Saskatchewan. The delineated region was stratified, based on geomorphic characteristics, into three main textural classes. Within these three main textural areas, different land uses were represented: clay loam (fertilized wheat and pasture sites), fine sandy loam (fertilized canola site), and sandy (fertilized oat, alfalfa, and forest sites). Similar to the landscape-scale approach employed by Pennock *et al*. (1992), a systematic grid design was employed to quantitatively characterize, at each study site, the different landform complexes. For the purpose of this study and based on the soil characteristics of the sites, two landform complexes were ascertained: shoulder complex and footslope complex. Ten sampling points were randomly selected from each of these landform complexes for measuring N20 emissions.

The N_2O emissions were measured *in situ* using sealed chamber method. The temporal sampling scheme extended from early spring to fall 1994: weekly in spring, thrice a month in summer, and once a month in fall. Together with N20 measurements, volumetric moisture content was measured. Available N was also monitored monthly (data not reported).

RESULTS AND DISCUSSION

Robertson (1993) noted that knowledge of the agricultural and other intensively managed landscapes as contributors to global N_2O fluxes is weak. Surprisingly, the temperate region sources are particularly poorly known and are suggested as one of the major contributors. Hence, there is a present call of sufficiently detailed investigations that would provide reliable information about the mechanisms underlying fluxes across landscapes.

If we need to address the significance of N_2O production to atmospheric chemistry, we must then use conceptual links as the basis to quantify the relationship between large-scale controlling factors and N20 emission activity. There are only few practical and conceptual tools available for directing experimental design of microbial processes at the landscape-, regional- and seasonal-scales. For N20 emission, the following is adapted from Groffman (1991):



Scales of Regulation

Figure 1. Conceptual tool for investigating N20 emission at a large scale.

At the cellular level, the most important controlling factor of N20 production is the soil aeration status. As the 02 supply gradually diminishes, the soil organic carbon and nitrogen availability become increasingly important. The hierarchy of importance of these factors was observed at the field-scale (Burton and Beauchamp, 1985; Davidson and Swank, 1986) and at the landscape-scale (Van Kessel et ***al.,*** 1993). In a soil landscape system, it has been recognized that topographic variation strongly influences soil type due to its effect on the movement and distribution of water and dissolved materials in the landscape (Pennock etal 1987). Soil type, which is a strong controller of organic matter levels, moisture dynamics, and nitrogen mineralization (Jenny 1980), is also an important landscape-scale controller of N20 emission. At the regional scale, distinct landscape units serve as the experimental units that are sampled to cover the range of conditions within the region. Geomorphology, land use, and climate (particularly precipitation) are identified as important regional-scale controlling factors of N20 emission. The distribution of glacial landforms and alluvial deposits strongly influence soil texture, fertility, microclimate, and other factors that influence soil type (Swanson *et al.,* 1988).

Spatial pattern of N_2O emission

At the landscape scale, spatially distinct N_2O fluxes were associated with the landform complexes; higher fluxes occurred on the footslope than on the shoulder complexes (Figs. 2a to 2d). These support earlier findings which demonstrated that within a particular soil landscape system, topography is the basic control of spatial variability in the landscape (Elliott and de Jong, 1992; Pennoc ***et al.*** 1992; Van Kessel ***et al.,*** 1993). The role of topography has been attributed to its strong influence on the more basic pedologic and hydrologic processes which regulate the soil factors directly controlling the process at the cellular level. The lower N20 emission activity associated with the shoulder than with the footslope complexes reflect the effects of topographically-induced water redistribution and better drainage condition of the soils on the upper than on the lower landscape positions.

Moreover, the strong influence of topography to soil type and water redistribution would affect plant growth and, consequently, carbon and nitrogen cycling dynamics in the landscape. These results also indicates the importance of considering landscape-scale variation in developing a predictive model for quantifying N_2O emission.

Figure 2. Spatial and seasonal patterns, of N_20 emission at (a) clay loam - wheat, 9B0 clay loam - pasture, (c) fine sandy loam - canola, (d) sandy sites (footslope complex), and (e) of soil moisture content at clay loam - wheat site.

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The comparison among the six sites revealed that clay loa -mwheat an dfind sandy loam - canola sites emitted higher N20 than the rest of the sites (Figs. 2a and 2c). The clay loam -pasture site had generally higher N20 fluxes than any of the sandy sites, except when the sand y oat site was fertilized with nitrogen (Figs. 2b and 2d). Based on the geomorphological stratification of the region (by large-scale textural classes), the lower N20 emissions in the sandy area than the fine-textured areas reflect their differences in soil fertility and moisture retention characteristics. In addition, based on the land use patterns, the lower N20 emissions of the pasture and forest sites than the cultivated, fertilized sites could be due to their conservative nitrogen cycle which may have caused its low available nitrogen accumulation (data not shown), and hence low amounts of substrate for N20 production. The results also indicate the importance of stratifying a region into representative landscape units reflecting geomorphic a landuse differences since these areas may differ in their cycling of energy and nutrients.

Seasonal pattern of N20 emission

To assess the temporal stability of the aforementioned spatial pattern, N20 emission was monitored at the seasonal-scale. In the six sites, the spatial pattern remained consistent throughout the seasons. In the clay loam area, considerable N20 emission activity was observed during the early spring, with the activity detected earlier on the shoulder than on the footslope complexes (Fig. 2a) and earlier in the wheat than in the pasture sites (Fig 2b). These were due to the fact that the snow had melted and the soil had thawed earlier on the shoulder than on the footslope complexes, and earlier in the wheat than in the pasture sites. In the clay loam -pasture site, the spring pulse of activity was the highest throughout the seasons. A spring pulse of N20 emission activity has also been observed by others (Groffman and Tiedje, 1989). This was attributed to the high soil moisture content from snowmelt, and increase in organic carbon and nitrogen from lysis of microbial cells as a result of freezing and thawing.

The activity decreased when the soil became dry during the late spring (Fig 2a),. and N20 emission did not increase even with nitrogen fertilization. However, nitrogen fertilization followed by rainfall triggered N20 emission, specially during the early summer when the highest and most frequent rainfall events occurred

(Figs. 2a, 2c, and 2d[sandy - oat]). In the clay loam - wheat site, the N20 fluxes resulting from N fertilization followed by rainfall were higher than the early spring fluxes (Fig. 2a). The results were similar with the earlie findings which revealed that nitrogen fertilization followed by rainfall increased N_2O emissions due to increase in nitrogen availability and anaerobiosis in the soil (Van Kesse *et al.,* 1993). The activity decreased towards the end of summer and virtually ceased in fall, which was attributed to the low soil moisture contents (Fig. 2e) that might have hindered N20 production.

The seasonal variability of N_2O emission is often attributed to changes in soil regulatory factors. Soil aeration status, which has been identified as the most important controlling factor of N20 production, is usually indexed by soil water content. Increases in soil water content promote N20 production not only by reducing 02 diffusion, but also by stimulating microbial activity (Davidson and Swank, 1986) and promoting diffusion of NO_3^- and soluble carbon (Vermes and Myrold, 1992). In the clay loam -wheat site, the soil moisture content followed similar landscape and seasonal patterns as the N20 emission (Figs. 2a and 2e). The results indicate that both the higher moisture content on the footslope than on the shoulder complexes, and the high precipitation during early spring and early summer tended to increase N20 emission. This also signified that topography and climate are large-scale controlling factors of N20 emission activity through their influence on the soil aeration status.

CONCLUSIONS

In cultivated landscape' systems, nitrogen fertilization followed by rainfall triggered N20 emission, and contributed the high fluxes observed in early summer. On the other hand, in uncultivated landscape systems, the pulse of N20 emission activity in early spring is of significant importance for quantifying annual flux.

The landform complexes proved to be useful sampling units in characterizing the variability of N20 emission at the landscape-scale. The seasonal variation of N20 emission is controlled by soil and climatic factors. Becaus the dominant controlling factor may vary during the seasons, it is therefore essential that predictive models for quantifying N20 emission should reflect not only the landscape variability but also the seasonal variability of the process.

The differences in N20 emission activity among the six landscape systems justify the importance of geomorphology and land use as the basis for identifying representative landscape unit is a region to come up with reliable regional flu estimate.

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LITERATURE CITED

Burton, D.L. and E.G. Beauchamp. 1985. Denitrification rate relationships with soil parameters in the field. Comm. Soil Sci. Plant Anal 16(5):539-549.

Davidson, E.A. and W.T. Swank. 1986. Environmental parameters regulating gaseous nitrogen losses from two forested ecosystems via nitrification and de&&cation. Appl. Environ Microbiol. 52:1287-1292.

Elliott, J.A. and E. de Jong. 1992. Quantifyin g denitrification on a field scale in hummocky terrain. Can. J. Soil Sci 72:21-29.

Groffrnan, P. M. 1991. Ecology of nitrification and denitrification in soil evaluated at scales relevant to atmospheric chemistry, pp. 201-217 IN: J. E. Rogers and W. B. Whitman (eds.) Microbial Production and Consumption of Greenhouse Gases: Methane, Nitrogen Oxides and Halomethanes. Am .Soc. Microbiol. Washington, D.C.

Groffman, P. M., and J. M. Tiedje. 1989. Denitrification in north temperate forest soils: spatial and temporal patterns at the landscape and seasonal scales. Soil Biol. Biochem. 21:613-620.

Hutchinson, G.L. and E.A. Davidson. 1993. Processes for production and consumption of gaseous nitrogen oxides in the soil In : L.A. Harper at al. (Eds.). Agricultural Ecosystem Effects on Trace Gases and Global Climate Change . ASA, CSSA, SSSA, Madison, WI .ASA Spec. Publ. No. 55.79-93.

Jenny, H. 1980. The Soil Resource: Origin and Behavior. Springer-Verlag, New York.

Mosier, A. R., M. Stillwell, W. J. Patton, and R. G. Woodmansee. 1981. Nitrous oxide emissions from a native short grass prairie. Soil Sci Soc. Am. J . 45:617-619.

Mosier, A. R., W. J. Patton, and G. L. Hutchinson. 1983. Modelling nitrous oxide evolution from cropped and native soils, pp. 229-241 IN: R. Hallberg (ed.) Environ. Biogeochem. Ecological Bulletin 35, Stockholm.

Pennock, D.J., B.J .Zebarth and E. de Jong. 1987 .Landform classification and soil distribution in hummocky terrain, Saskatchewan, Canada. Geoderma. 40:297-3 15.

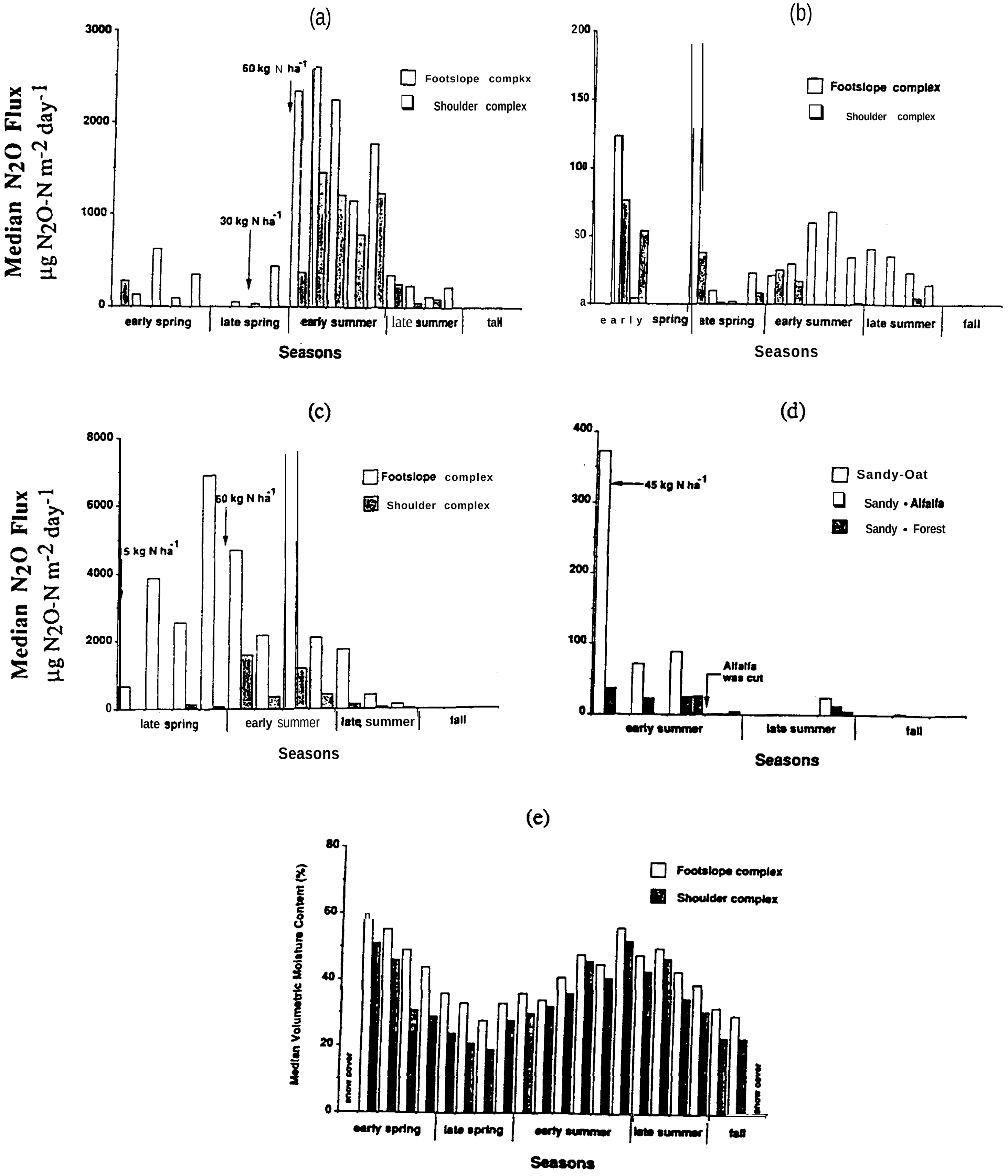
Pennock, D.J., C. van Kessel, R.E. Farrell and R.A. Sutherland. 1992. Landscape-scale variations in denitrification 56:770-776.

Robertson, G. P. 1993. Fluxes of nitrous oxide and other nitrogen trace gases from intensively managed landscapes: A global perspective IN: L. A. Harper et al. (Eds.). Agricultural Ecosystem Effects on Trace Gases and Global Climate Change .ASA, CSSA, SSSA, Madison, WI .ASA Spec. Publ. No. 55. 121-132.

Seiler, W., and R. Condrad. 198 1. Field measurements of natural and fertilizer induced N20 release rates from soils. J. Air Pollut. Control Asso. 3 1:767-772.

Swanson, F. J., T. K. Krazt, N. Caine, and R. G. Woodmansee. 1988. Landform effects on ecosystem patterns and processes. Bioscience 38:92-98.

Van Kessel, C., D.J. Pennock and R.E. Farrell. 1993. Seasonal variations in denitrification and nitrous oxide evolution at the landscape scale. Soil Sci. Soc. Am J. 57:988-995.



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