Spatial and Temporal Variations of N_2O Evolution at the Landscape Scale as affected by Land Use

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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. Soils generally act as source of N_2O, but the actual rates of N_2O emission and the controls on these rates remained poorly understood.

As a pre-requisite to quantify large-scale N_2O emissions over a long term range, this study was conducted to determine the landscape- and seasonal-scale patterns of N_2O emission. Nitrous oxide emissions were assessed at a hummocky glacio-lacustrine landscape in the Black soil zone. The study area was divided into three agronomic practices : an unfertilized canola site, a conventional fallow site, and a pasture site. A systematic grid design was employed at each site and N_2O emission was monitored using closed chamber method.

A clear landscape-scale pattern of N_2O emission was observed in the unfertilized canola and conventional fallow sites; lower landscape positions showed higher N_2O flux than the upper landscape positions. This pattern remained consistent throughout the season, with increased in N_2O flux towards the mid-growing season (summer), decreased towards the end of the growing season (early fall), and virtually ceased by the onset of frost (late fall). Of the three sites tested, the pasture site showed the lowest N_2O emission and activity was only observed during the summer samplings. Soil respiration and moisture content followed similar spatial and temporal patterns as N_2O emission. Results indicate that N_2O production is controlled at the landform level by soil factors and at seasonal level by precipitation and temperature. Such relationships might be useful in generating a spatially-distributed model for quantifying N_2O emission.

Key words : landscape scale, spatial pattern, seasonal pattern, N_2O evolution

INTRODUCTION

The loss of nitrogen from the soil in the form of N_2O is important both agronomically and environmentally. Nitrous oxide represents the unrecoverable loss of nitrogen because unless it is further reduced to N_2, it can only be re-fixed and cycled back in to the soil-plant system. It has also been recognized as a potent and long-lived greenhouse gas (Duxbury et al., 1993), and is involved in the destruction of ozone (McElroy et al., 1977).

Although N_2O emission has been well characterized in the laboratory and plot-scale studies, considerable uncertainties still exist regarding its significance in many ecosystems and factors regulating it *in situ*. Several studies have been conducted to investigate relationships with factors influencing N_2O production for the purpose of improving the efficiency of N utilization and understanding global behavior of N_2O emissions from soils. The inherently high spatial and temporal variabilities of the process hinder such attempts of establishing predictive relationships. The increasing body of knowledge has signified that large scale and long term investigation may yield more reliable informations on relationships of N_2O production to soil regulatory factors than point-specific measurements.

Knowledge on the spatial and temporal variabilities at landscape and seasonal scales is important not only for quantifying N_2O emission but also for developing site-specific management strategies. This study was conducted to determine the soil factors, and landscape- and seasonal-scale patterns of N_2O emission under different land uses.

METHODOLOGY

In 1993, a landscape-scale study was conducted in a loam-textured Chernozemic Black soil characterized by a hummocky terrain (5 - 10 % slope) near St. Louis, Saskatchewan. Three land use types were studied : unfertilized canola, conventional fallow and pasture sites. The fallow site was fallowed beginning in July. The pasture site was cultivated up to twenty years ago and has been a pasture since then. Similar to the method employed by Pennock et al. (1992), in each of these sites, a systematic grid design was used wherein the intersections of the grid matrix determined the sampling points. Each of the sampling points were quantitatively classified into its corresponding landform element. For the purpose of this study and based on the soil characteristics of the study sites, two landform element complexes were ascertained : shoulder and upper level complex (SHC) and footslope and lower level complex (FSC).

The N_2O emissions were measured *in situ* using closed chamber. The temporal sampling scheme covered the period from late spring to late fall, and measurements were taken after every significant rainfall event (>7 mm). Together with N_2O emission measurement, volumetric soil moisture and soil respiration were measured, as described elsewhere (van Kessel et al., 1993). Available N (NH_4^+ and NO_3^-) was monitored monthly (data not reported).

RESULTS AND DISCUSSION

Among the biotic and abiotic processes involved in the production of N_2O in the soil, nitrification and denitrification are of major significance from the environmental view point (Hutchinson and Davidson, 1993). It is expected that the highest N_2O emission should occur under slightly aerobic but considerably low-O_2 conditions. Under these conditions nitrifiers, limited in their source of O_2, will produce N_2O and denitrifiers are inhibited by the presence of relatively available O_2 which will result in the production of N_2O as the dominant end product. Reported works on N_2O emission studies have either used an indirect method of quantifying the flux (i.e., soil core incubation method) or employed spatial scales inadequate for optimizing sampling efforts. This is because neither N_2O evolution nor its quantification is the main focus of the studies. For the purpose of the present study, an *in situ* and direct measurement of N_2O emission was carried out using the closed chamber method. This has been proven to be efficient and to reduce potential error associated with disturbance of study site that might alter its N_2O production activity (Goodroad and Keeney, 1984; Davidson and Swank, 1986).

Spatial pattern of N_2O emission activity

At the landscape scale, spatially distinct rates of N_2O emission were associated with the landform complexes; significantly higher rates occurred at FSC than at SHC (Fig. 1a). These support earlier findings which demonstrated that within a particular ecosystem or vegetation biome, topography is the basic control of spatial variability in the landscape (Elliott and de Jong, 1992; Pennock et al., 1992; van Kessel et al., 1993). The role of topography corresponds to what Robertson (1989) termed as distal control of N_2O production activity. That is, topography has strong influence on the more basic hydrologic and pedologic processes which regulates the soil factors directly controlling the process at cellular level. It has been recognized that geomorphic variation in a soil landscape system strongly influences soil type and water redistribution (Pennock et al., 1987), which in turn affect plant growth and, hence, N cycling dynamics in the landscape. These results also indicates the importance of taking into account landscape-scale differences in developing models for quantifying N_2O emission.

Seasonal N_2O evolution

To assess the temporal stability of the aforementioned spatial pattern, N_2O emission was monitored at the seasonal scale. It was observed that the spatial pattern remained consistent throughout the season. Low activity was detected under the dry condition of late spring (May and early June, Fig. 1.) and generally increased towards the mid-growing season (summer), which corresponded with the most frequent and highest rainfall events (climatic data not reported). These results were similar to the earlier study which revealed that precipitation triggered an increase in N_2O production activity as a result of an increase in anaerobiosis in the soil (van Kessel et al., 1993). The activity decreased towards the end of the growing season and virtually ceased by the onset of frost (Nov. 11), which was attributed to the low soil moisture (Fig.2a) and temperature (data not shown) that may have hindered microbial activity.

The comparison among the three sites at the landscape and seasonal scales revealed that no significant differences existed between the unfertilized canola and conventional fallow sites, while the pasture site consistently had the lowest N_2O emission rates. At the pasture site, N_2O emission was only detected during the summer samplings wherein the climatic condition was also most favorable for N_2O production activity. The lowest N_2O emission in the pasture site could be due to its conservative N cycling which may have caused its low available N accumulation (data not shown) and hence low amounts of substrate for N_2O production.

In achieving a regional-scale estimate of flux, the results also indicates the importance of stratifying a region into representative landscape reflecting differences in vegetation biome/land use since these areas may differ in their cycling of energy and nutrients.

Relationship to controlling factors

The seasonal variability of N_2O evolution is often attributed to changes in soil regulatory factors. Studies showed that the most important controlling factor of N_2O production is the aeration status in the soil (Burton and Beauchamp, 1985; Davidson and Swank, 1986; van Kessel et al., 1993), which is often indexed by soil water content. Soil water functions to promote N_2O production by reducing O_2 diffusion, stimulating microbial activity and promoting diffusion of nitrate and soluble carbon. The soil moisture content and soil respiration in the unfertilized canola site followed similar landscape and seasonal-scale patterns as N_2O emission (Fig.1a and 2). Similar results were obtained in the conventional and pasture sites (data not shown). These results indicate that both the higher moisture content at the FSC than at SHC, as a consequence of topographical control on moisture redistribution in the landscape, and the higher precipitation and temperature in summer than in late spring and fall tended to increase microbial activity which resulted in an increased N_2O emission. This was supported by the significant Spearman correlation coefficients between N_2O emission and soil moisture and respiration from June 14 to July 8 (data not shown), wherein the higher rates occurred (Fig. 1a and 2).

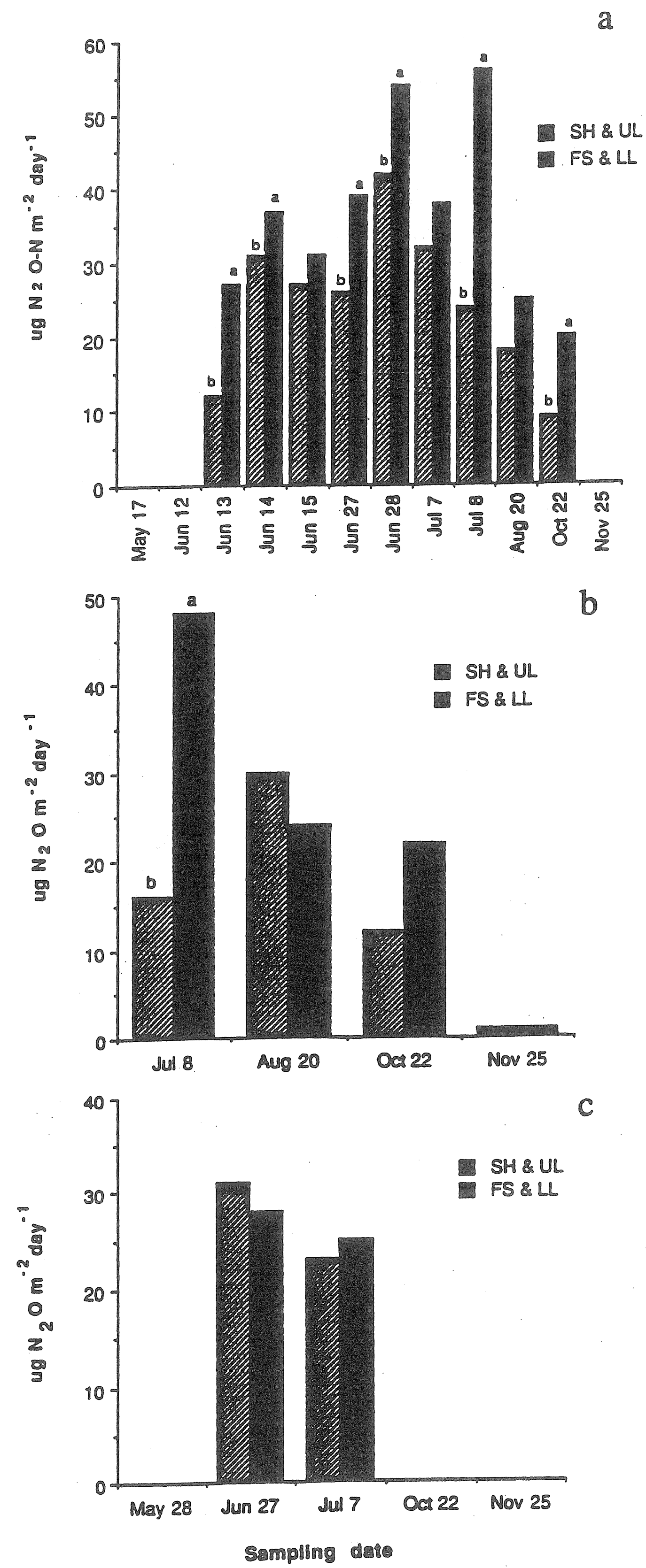

Fig. 1. Median rates of N_2O emission in the (a) unfertilized canola, (b) conventional fallow, and (c) pasture sites. Letters at each sampling date denote significant difference using Mann-Whitney U test at $\alpha = 0.20$.

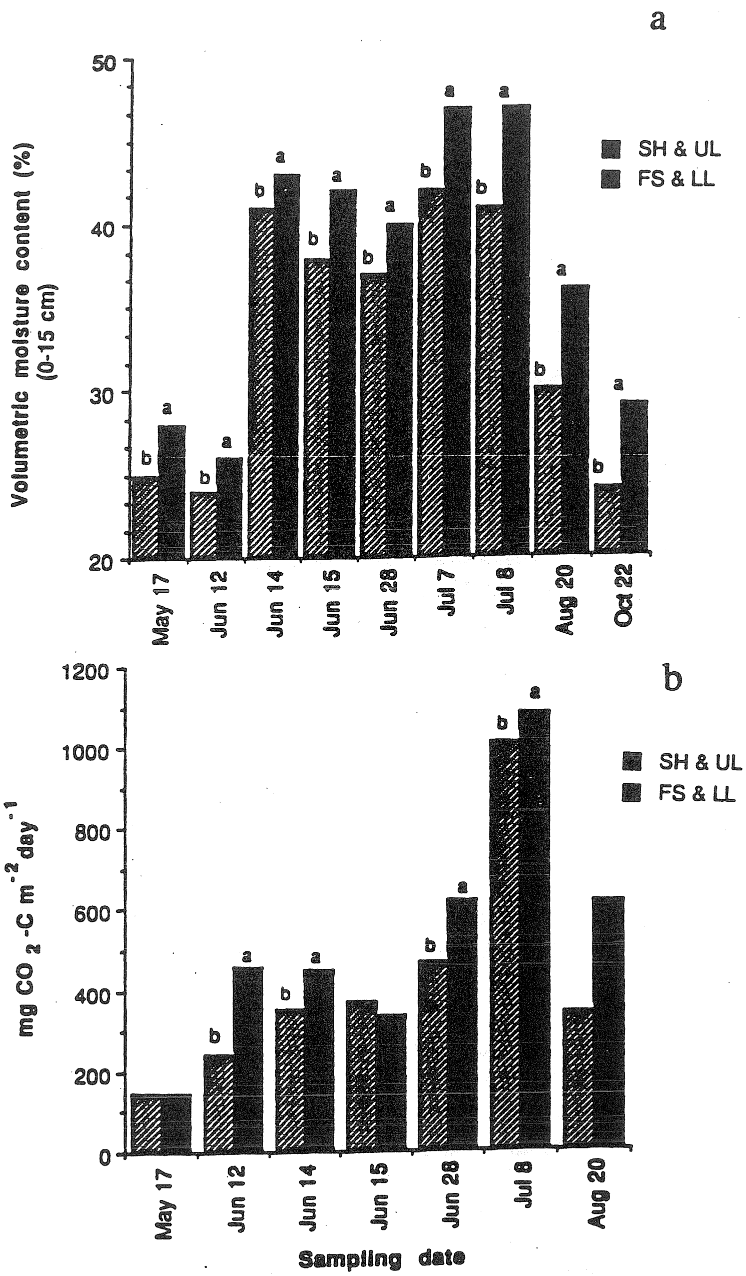

Fig. 2. Median volumetric moisture content (a) and rates of soil respiration (b) in the unfertilized canola site. Letters at each sampling date denote significant difference using Mann-Whitney U test at $\alpha = 0.20$.

CONCLUSION

The landform element complexes proved to be useful sampling units in characterizing the variability in the landscape. Within a landscape system, seasonal variation of N_2O emission is controlled by soil and environmental factors. Because the dominant controlling factor may vary during the season, it is therefore essential that predictive model for N_2O emission should reflect not only the landscape variability but also the seasonal variability of the process.

Nitrous oxide evolution, soil moisture and soil respiration exhibited similar landscape-scale patterns that remained consistent throughout the season. This relationships might be useful in generating a spatially-distributed model for quantifying N_2O emission at the landscape scale.

The differences in N_2O emission rates among the land uses indicate the importance of investigating representative landscapes in a region to come up with reliable regional flux estimate.

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