NITROUS OXIDE PRODUCTION AND CONSUMPTION IN PEAT SOILS

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Abstract. Nitrous oxide can be produced in soils by biological or chemical processes in which nitrogen compounds are transformed. The occurrence and course of these processes are affected by different factors, e.g. temperature, pH, aeration of the soil, availability of organic substances and availability of inorganic nitrogen (e.g. nitrate and ammonium). How these factors affect nitrogen transformations was investigated in laboratory experiments. In these experiments biological denitrification was probably responsible for observed flushes of net nitrous oxide production.

The observed effects of the above-mentioned factors qualitatively confirmed the results described by various authors for soils other than peat.

A denitrification simulation model to explain the results is briefly discussed. This model was developed to describe the underlying biological processes. Suggestions are given on how to develop a field scale model to explain nitrous oxide emissions from pastures.

1. Introduction

Nitrous oxide (N_2O) is one of the greenhouse gases. At this moment its direct contribution to the enhanced greenhouse effect is smaller than that of carbon dioxide (CO_2) and methane (CH_4). The N_2O concentration increase is responsible for about 5 % of the enhanced greenhouse effect (Bouwman, 1990). The total global N_2O production corresponds with 14 ± 7 (Tg N) y^{-1}, the total global sink corresponds with 9 ± 2 (Tg N) y^{-1} (Seiler and Conrad, 1987). More than 50 % of the production is attributed to soil processes. Cultivated organic (peat) soils deserve special attention, because of their relatively high N_2O emission rate (Bouwman, 1990). In this research, a part of the 'Integrated N_2O grassland project' in The Netherlands, the role of different factors affecting N_2O-production/consumption in peat soil was investigated. The factors that were varied for incubated soil samples from 'R.O.C. Zegveld', Zegveld, The Netherlands ($52^{o}07'N$ $4^{o}52'E$) were: collection location, collection depth, incubation temperature, kind and amount of applied N fertiliser and initial incubation conditions (aerobic versus anaerobic). The way in which these different factors affect nitrous oxide dynamics probably reflects their effect on one or more of the main soil processes involved: biological denitrification, chemical denitrification and biological nitrification.

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2. Materials and methods

Some major guidelines for the experiments were:
- the influence of the collection action on the results should be minimal. Therefore, the collected material was stored some weeks before starting the incubation,
- the stored soil material should not be subject to overall anaerobiosis during storage,
- the prepared soil material should have a relatively homogeneous crumble size distribution (crumble diameter below about 1 cm),
- the crumbles should be subjected to the same micro-environments; therefore inhomogeneities (gradients) caused by limited transport (diffusion, water transport) should be prevented,
- precautions to minimise the risk of gas leakages during the incubations should be taken.

EXPERIMENT 1

Peat soil from a grassland plot with relatively high groundwater table (plot 8B; average ground water table during the growing season 1992 was at a depth of 40 cm) was collected at 3 sites about 5 m apart in December 1992. From these sites (of about 20 cm x 30 cm), material was taken at depths of 2-8 cm and 25-30 cm. The soil was stored in open plastic bags in the dark at about 7 ^{o}C. Five weeks after the collection, the soil was cautiously crumbled by hand and stored in the same way as before. Five days later, the first incubation experiment started. Covered petri-dishes were used. The experimental procedure of Leffelaar and Wessel, 1988, was followed, with some minor modifications (i.e. (a) we used 30 g of field wet soil in each petri-dish and (b) we flushed at the start of the incubation with either an 80 % neon (Ne) / 20 % oxygen (O_2) mixture (aerobic initial conditions) or 100 % Ne (anaerobic initial conditions)). The petri-dishes were incubated in the dark at either 7 ^{o}C or 20 ^{o}C. Over a period of 24 days the gas composition was followed at intervals varying from 1 day to 7 days. Gas samples of 100 µl were taken and analysed for Ne, N_2O, molecular nitrogen (N_2), CO_2 and O_2 on a gas chromatograph with TCD (Leffelaar, 1986) (estimated detection limit for N_2O: 0.1 %). During the experiment the gravimetric water content of the soil samples was determined at day 0, 7 and 24 (Houba *et al.*, 1985). At several moments, soil samples were taken away and extracted with 0.01 M calcium chloride ($CaCl_2$•2 H_2O) (Houba *et al.*, 1985) for the determination of pH and contents of nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+).

In this first experiment the effect on N_2O results of following factors were investigated:

1. *location*: comparison of samples from the three sites,
2. *depth*: comparison of samples from the 2-8 cm and the 25-30 cm layer, respectively,
3. *temperature*: comparison of samples incubated at 7 ^{o}C and 20 ^{o}C, respectively,
4. *kind of N fertiliser combined with different initial conditions*: comparison of samples with (i) no added fertiliser, (ii) an amount of calcium nitrate ($Ca(NO_3)_2$•4 H_2O) corresponding with 150 (mg N)/(kg dry soil), (iii) an amount of ammonium sulphate ($(NH_4)_2SO_4$) corresponding with 150 (mg N)/(kg dry soil), incubated at either anaerobic or aerobic initial conditions.

EXPERIMENT 2

For the second experiment, peat soil from two different grassland plots was used. One of the plots was plot 8B, the plot of Experiment 1. The other, plot Bos 6, had a relatively low ground water table (average ground water table during the growing season 1992 was at a depth of 55 cm). On each plot, soil material was collected at depths of 2-8 cm at four sites in March 1993. The soil was stored in the dark at about 7 ^{o}C. Three weeks later, the soil was crumbled and another week later the experiment started. In this experiment mixed soil samples with soil from either plot 8B or plot Bos 6 were used. The petri-dishes for this experiment were prepared as in Experiment 1, except that we flushed with a 97 % Ne / 3 % O_2 mixture, and that the soil was incubated at 15 ^{o}C. All determinations were performed as described for Experiment 1.

In Experiment 2 the effects of the following factors on the N_2O results were investigated:

1. *location and kind of N fertiliser:* comparison of samples from plot 8B and plot Bos 6, respectively, incubated with:
   (a) no added fertiliser,
   (b) calcium ammonium nitrate, consisting of ammonium nitrate (NH_4NO_3) and chalk ($CaCO_3$) and containing 27 % of nitrogen (N) on a mass basis, in an amount corresponding with 150 (mg N)/(kg dry soil),
   (c) $Ca(NO_3)_2$•4 H_2O in an amount corresponding with 150 (mg N)/(kg dry soil),
2. *amount of nitrate fertiliser:* comparison of samples from plot 8B incubated with amounts of $Ca(NO_3)_2$•4 H_2O corresponding with:
   (i) no added N,
   (ii) 75 (mg N)/(kg dry soil),
   (iii) 150 (mg N)/(kg dry soil),
   (iv) 300 (mg N)/(kg dry soil).

3. Results and discussion

No changes of the soil water content of the samples were observed. The time courses of NO_3^-, N_2O and N_2 were qualitatively similar in all incubations. A decrease of the soil NO_3^- content at the start of the incubation was followed by an increase and subsequent decrease of N_2O and finally by an increase of N_2 in the gas samples (Figure 1). These findings basically agree with those obtained for soils other than peat (e.g. Cooper and Smith, 1963; Leffelaar and Wessel, 1988). Contrary to these authors, however, we did not find substantial amounts of NO_2^-. Also the final amount of nitrogen in N_2 at the end of the incubation was much larger than the amount of nitrogen in NO_3^- at the start. We concluded that nitrogen from another source than the initially present amounts of nitrate or ammonium is transformed into N_2 (probably mineralisation plays an important role).

In our experiments denitrification was probably more important for the control of N_2O dynamics than nitrification. The results for the initially aerobic samples of Experiment 1 strongly support this statement. In these samples a decrease of the amount of NH_4^+

between day 0 and day 3, probably due to nitrification,was observed. This decrease, however, was not accompanied by the occurrence of observable N_2O concentrations.

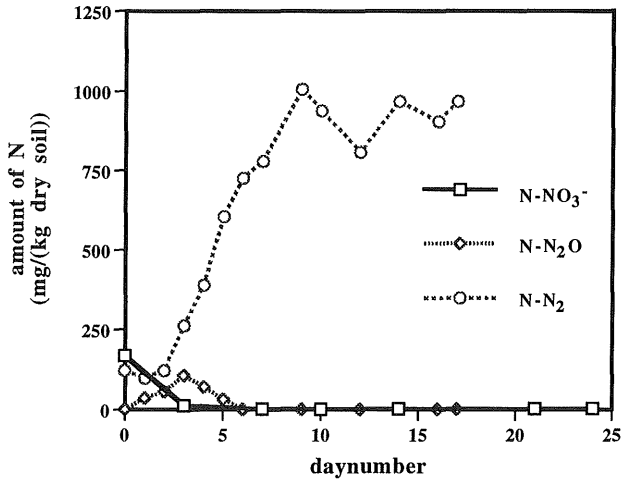

Figure 1. Amount of nitrogen (N) (in mg /(kg dry soil)) present in nitrate (NO_3^-), nitrous oxide (N_2O) or molecular nitrogen (N_2) versus the number of the day since the start of the incubation of a sample from plot 8B in Experiment 1. The sample was anaerobically incubated at 20 °C after the addition of calcium nitrate in an amount corresponding with 150 (mg N)/(kg dry soil).

EXPERIMENT 1

1. Location

No significant differences were found between the samples from the 3 spots on plot 8B which were anaerobically incubated at 20 °C. This result was not a priori expected on the basis of literature in which denitrification rates in *field* measurements showed a high spatial variability (e.g. Christensen *et al.*, 1990).

2. Depth

Substantial differences were found between mixed soil samples from different depths incubated anaerobically at 20 °C. The samples from the 25-30 cm layer showed the lowest CO_2 formation rate and the lowest N_2O peaks. These differences were probably caused by a decrease of the microbial (denitrification) activity with depth (see also Firestone, 1982).

3. Temperature

For the samples from the 2-8 cm layer anaerobically incubated at 7 °C a lower CO_2 formation rate and a slower increase and decrease of N_2O were found than for the samples incubated anaerobically at 20 °C. Such temperature effects have been discussed by various authors (e.g. Cooper and Smith, 1963; Firestone, 1982).

4. Kind of N fertiliser under different initial conditions

Under anaerobic initial conditions addition of NO_3 fertiliser resulted in a longer presence of N_2O in the sample atmospheres when compared with samples in which no fertiliser or

NH_4 fertiliser had been added (incubation temperature 20 °C). The effect of nitrate on the duration of the presence of N_2O has been observed before and was explained by enhanced production of N_2O and/or inhibition of the reduction of N_2O (Cleemput *et al.*, 1988).
In the initially aerobic samples a decrease of the O_2-percentage from about 20 % at day 0 to less than 5 % at day 12 was observed.
Comparison of the influence of different initial conditions on the N_2O course showed that:

1. in the anaerobically incubated samples N_2O peaks occurred directly after the beginning of the incubation; after aerobic initial conditions the N_2O peaks only occurred when the O_2 percentage had fallen below 5,
2. for the case without added fertiliser, aerobic initial conditions resulted in a longer presence of N_2O and higher N_2O peaks when compared with anaerobic initial conditions,
3. under aerobic initial conditions no differences were found between the N_2O courses of the samples with either added NO_3 fertiliser or added NH_4 fertiliser.

These observations suggest that denitrification is the main source of N_2O in our samples and that in the initially aerobic samples nitrification (without observable N_2O concentrations) precedes denitrification (accompanied by observable N_2O concentrations).

EXPERIMENT 2

1. Location and kind of N fertiliser

Small differences were observed between the N_2O courses in corresponding samples from the two plots. These differences, peak heights and N_2O presence durations, can possibly be explained by a somewhat higher denitrification activity in the samples from the plot with the lowest ground water table. For this plot the clearest differences between N_2O courses in the case of different fertiliser additions occurred: no addition of N fertiliser resulted in presence of very small amounts of N_2O during a short period, addition of calcium ammonium nitrate resulted in a longer period of N_2O presence, while addition of calcium nitrate resulted in the longest period of N_2O presence.

2. Amount of nitrate fertiliser

We found that the duration of the presence of N_2O increased with the amount of added nitrate fertiliser. This result is consistent with the results of experiment 1 and the results of Cleemput *et al.*, 1988.

MODELLING

In order to be able to explain the effect of different factors on N_2O production/consumption in incubated peat soil quantitatively, a denitrification simulation model describing the *underlying biological processes* of Leffelaar and Wessel, 1988, will be adapted. Modifications will be made to model the effects of temperature, origin of the sample (sampling depth) and mineralisation . This model does *not* describe *transport processes* (diffusion, water transport, etc.)
For the development of a *field scale* model to predict field emissions/immissions of N_2O an approach based on empirical relations between local physico-chemical conditions and

measured local N_2O fluxes seems more appropriate. In this approach a field is considered as an ensemble of physico-chemically characterised area units, all having their own contribution to N_2O emission/immision. These units are distributed according to a (measured/chosen) distribution function. The state of the units will change as a result of among others *transport processes*, which also have to be modelled.

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