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Fluxes of CH_4 and N_2O in aspen stands grown under ambient and twice-ambient CO_2

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Abstract

Elevated atmospheric CO_2 has the potential to change below-ground nutrient cycling and thereby alter the soil-atmosphere exchange of biogenic trace gases. We measured fluxes of CH_4 and N_2O in trembling aspen (*Populus tremuloides* Michx.) stands grown in open-top chambers under ambient and twice-ambient CO_2 concentrations crossed with 'high' and low soil-N conditions.

Flux measurements with small static chambers indicated net CH_4 oxidation in the open-top chambers. Across dates, CH_4 oxidation activity was significantly ($P < 0.05$) greater with ambient CO_2 (8.7 μg CH_4-C m^{-2} h^{-1}) than with elevated CO_2 (6.5 μg CH_4-C m^{-2} h^{-1}) in the low N soil. Likewise, across dates and soil N treatments CH_4 was oxidized more rapidly ($P < 0.05$) in chambers with ambient CO_2 (9.5 μg CH_4-C m^{-2} h^{-1}) than in chambers with elevated CO_2 (8.8 μg CH_4-C m^{-2} h^{-1}). Methane oxidation in soils incubated in serum bottles did not show any response to the CO_2 treatment. We suggest that the depressed CH_4 oxidation under elevated CO_2 in the field chambers is due to soil moisture which tended to be higher in the twice-ambient CO_2 treatment than in the ambient CO_2 treatment.

Phase I denitrification (denitrification enzyme activity) was 12–26% greater under elevated CO_2 than under ambient CO_2 in the 'high' N soil; one sampling, however, showed a 39% lower enzyme activity with elevated CO_2. In both soil N treatments, denitrification potentials measured after 24 or 48 h were between 11% and 21% greater ($P < 0.05$) with twice-ambient CO_2 than with ambient CO_2. Fluxes of N_2O in the open-top chambers and in separate 44 cm^2 cores $\pm$N fertilization were not affected by CO_2 treatment and soil N status.

Our data show that elevated atmospheric CO_2 may have a negative effect on terrestrial CH_4 oxidation. The data also indicated temporary greater denitrification with elevated CO_2 than with ambient CO_2. In contrast, we found no evidence for altered fluxes of N_2O in response to increases in atmospheric CO_2

Introduction

Elevated concentrations of atmospheric CO_2 have the potential to increase rates of below-ground as well as above-ground plant production in terrestrial ecosystems (Rogers et al., 1994). For example, Pregitzer et al. (1995) found that growth and turnover of fine roots of aspen trees increased under twice-ambient CO_2 and that inputs of carbon to soil roughly doubled. Similarly, Rouhier et al. (1996) observed increased root production and rhizodeposition from chestnut seedlings grown under elevated CO_2.

Increased C allocation below-ground in response to elevated CO_2 is likely to fuel below-ground heterotrophic processes and increase microbial biomass (Klironomos et al., 1996; Niklaus and Körner, 1996; Rice et al., 1994; Schenk et al., 1995; Zak et al., 1993) and soil respiration (Niklaus and Körner, 1996; Ross et al., 1995, 1996). Microbial responses to elevated CO_2 vary and may not be distinct in systems with low nutrient availability (Klironomos et al., 1996; Niklaus and Körner, 1996). Although some have sug-

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gested that increased below-ground productivity may reduce nutrient availability through increased sequestration in microbial biomass (Diaz et al., 1993), others (e.g. Rice et al., 1994) note that soil nutrient turnover may increase if the labile carbon pool increases. In accordance with this postulate, Zak et al. (1993) observed greater short-term net mineralization under *Populus grandidentata* grown with elevated CO_2, but, in contrast Ross et al. (1995, 1996) found that soil N availability was apparently unaffected by growing grass clover pastures under elevated CO_2.

In addition to producing fundamental changes in net primary productivity and soil nutrient cycling, CO_2 enrichment also has the potential to increase plant water-use efficiency. Working with tallgrass prairie systems, Owensby et al. (1993) and Rice et al. (1994) demonstrated that growth responses by both plants and microbes to elevated CO_2 were greater under dry conditions due to greater plant water-use efficiency than under ambient CO_2.

Soil N availability and moisture are strong regulators of microbial CH_4 oxidation and N_2O production in upland soils, so it is likely that ecosystem responses to elevated CO_2 will also include changes in fluxes of these trace gases (Robertson et al., 1989). Based on the literature, however, it is unclear whether CO_2 enrichment will feed back into the soil-atmosphere exchange of CH_4 and N_2O. More specifically, reduced N availability may provide a basis for higher methanotrophic activity (Schnell and King, 1994), whilst N gas production will be diminished. With increased soil moisture, on the other hand, CH_4 oxidation is likely to be diminished due to diffusional constraints (Dörr et al., 1993), whereas the reduced O_2 availability will induce conditions favourable for N_2O and CH_4 production. Hitherto very few studies (Hungate et al., 1997; Arnone and Bohlen, 1998; Ineson et al.,1998) have focused on this issue in upland soils.

The objective of this study was to determine the extent to which elevated CO_2 concentrations may change soil-atmosphere exchange of CH_4 and N_2O in trembling aspen (*Populus tremuloides* Michx.) stands grown under ambient and twice-ambient CO_2 conditions for two growing seasons in soils of low and 'high' N availability. Soil surface fluxes of CH_4 and N_2O, soil CH_4 oxidation and soil denitrification, respectively, was examined and compared with patterns of soil moisture and inorganic N across the different CO_2 and soil N treatments.

Materials and methods

Field studies

The experimental site is located at the University of Michigan Biological Station near Pellston, MI (45° 34′ N, 84° 4O′ W). Twenty open-top chambers were arranged in a randomized complete 2 × 2 factorial design (CO_2 × N fertility), with each treatment replicated five times; the experimental design was similar to that described in Pregitzer et al. (1995). Briefly, aspen trees were grown in 3.6 m square by 0.2 m deep open-bottom root boxes. Two contrasting N treatments were achieved by filling the boxes with 100% locally excavated topsoil (Kalkaska series, Typic Haplorthod) or a mixture of 20% top soil and 80% C horizon sand (Entic Haplorthod). These two soil treatments will be termed 'high' N (quotation marks to separate from a truly high N soil) and low N, respectively. Open-top chambers (3 m diameter by 3.4 m high) were placed on all root boxes during the growing season to manipulate atmospheric CO_2. The aspens were planted as cuttings two years prior to the experiment and had been exposed to ambient and twice-ambient atmospheric CO_2 for two growing seasons.

Sampling took place on three occasions in 1996: on May 1 prior to canopy development, on May 28 following canopy development, and on July 6 shortly before the experiment was terminated by destructive harvest.

Soil-atmosphere gas fluxes were measured using two-piece static gas chambers (Ambus et al., 1993). A 27 cm × 27 cm × 10 cm high aluminum frame was permanently installed 8 cm into the ground in each root box. When gas sampling took place, a 29 cm × 29 cm × 14 cm high white ABS plastic lid was fitted into a water filled groove on top of the aluminum base, providing a gas tight enclosure of 12 L. A rubber septum in the lid allowed gas sampling using a needle and syringe. The chamber remained sealed for 3 h and headspace samples were removed at 1 h intervals for analysis of CH_4 and N_2O.

Sampling involved a two step procedure. First, a 15-mL sample was withdrawn and used to flush a 2-mL crimp-sealed vial. Second, a 5-mL sample was withdrawn and stored in the now pressurized vial. Gas samples were analyzed within two days after collection. Gas fluxes were calculated as the linear increase or decrease in gas concentration inside the flux chamber over the 3 h sampling period.

Methane and N_2O were analyzed in 0.5 mL samples on a Hewlett Packard 5890 gas chromatograph equipped with flame-ionization (125 °C for CH_4) and electron-capture detectors (350 °C for N_2O).

Laboratory studies

At each field sampling soil samples (0-15 cm depth) was taken from each root box using a 20 mm dia. auger. In order to minimize disturbance of plant roots, only one auger sample was taken from each root box per samling time, and soil from the five replicate boxes was mixed to obtain adequate material for subsequent analysis. The mixed samples were sieved (<4 mm), and sub-samples were analyzed for gravimetric (105 °C; 24 h) water content, which was expressed as % of water filled pore space (WFPS; Linn and Doran, 1984) and 1 *M* KCl (soil:KCl=1:10 w/v) extractable NO_3^--N and NH_4^+-N (Alpkem Autoanalyzer). Soil total N and total C was determined by dry combustion (Carlo Erba CN Analyzer) and pH (air dry soil:water=1:2.5 w/v) were also measured; average values of these three parameters did not vary among CO_2 treatments and dates, and are expressed as means in Table 1.

Table 1. Total N, total C, and pH of soil from root boxes with 'high' and low N treatments, respectively. Data are means (n=6 ±SE) among CO_2 treatments and sampling dates

	Total (%)	Total C (%)	pH
Low N soil	0.04±0.002	0.29±0.03	6.3±0.04
'High' N soil	0.14±0.007	1.39±0.12	5.6±0.01

Methane oxidation and soil respiration was measured in 20 g field moist samples incubated with ambient laboratory air (2 ppm CH_4) in 160 mL sealed serum bottles at 20 °C. In addition, one set of samples was incubated with laboratry air with 100 ppm CH_4 achieved by injecting 1 mL of a 1% CH_4 in N_2 mixture into the bottle atmosphere. Headspace samples of 0.5 mL were withdrawn several times during a 72 h incubation period and analyzed immediately for CH_4 and CO_2. Carbon dioxide was analyzed on a Beckman Model 865 Infrared Gas Analyzer. Incubations for CH_4 oxidation and respiration were not performed on July 6.

Denitrification potential was determined in 10 g moist soil samples placed in 20 mL of nutrient solution (0.36 g KNO_3 L^{-1} and 1.25 g glucose L^{-1}) in 120 mL sealed serum bottles. The bottles were made anaerobic by evacuating and refilling them with N_2 three times. Acetylene was added to 10 % v/v (10 kPa). A 1-mL headspace sample was withdrawn at 1 h intervals during the 0-3 h of incubation and then again at 24 h and 48 h (May 28 and July 6), and stored in 3-mL N_2-flushed Venoject vials until analysis for N_2O.

An additional experiment was undertaken on July 6 to examine gas fluxes in response to fertilization. Two PVC cylinders, 16 cm long and 7.5 cm internal diameter, bevelled at one end, were pushed 10 cm into the ground in each root box and then removed by excavation. The cylinders were wrapped at the bottom with polyethylene film. Sixteen hours prior to gas measurements the two sets of cores were amended with either 45 mL of water $core^{-1}$ or 45 mL of an NH_4NO_3 solution (1 g N L^{-1}) $core^{-1}$, respectively. For gas flux measurements the cylinders were placed on trays filled to a depth of 1 cm with water, and the headspace around the individual cylinders was then sealed by 3.2 L metal cans placed open end down to achieve gas-tight seals. The cans were fitted with rubber septa for gas sampling, which was carried out as described for the field boxes. Pure N_2, equivalent to the amount removed for sampling, was injected into the cans to compensate for underpressure. Headspace samples were taken after 0, 2.5, 5, 7.5, 10, and 24 h of incubation at 20 °C.

Statistical analyses were performed on LOG-transformed data to meet the assumptions of equal variances. Multiple means were compared using Tukey's Studentized Range Test of Proc GLM at P=0.05 (SAS Institute, 1990).

Results and discussion

Methane

Net CH_4 consumption was observed at all samplings at rates from 3.5 to 14.5 μg C m^{-2} h^{-1} (Figure 1). These rates are at the low end of CH_4 uptake measured in temperate forest stands (Ambus and Christensen, 1995; Castro et al., 1995) but similar to rates observed in cropping systems (Ineson et al, 1998). The disturbance of the soil in the root boxes two years prior to the study may have depressed the CH_4 oxidation activity, as documented in comparative studies on cultivated and uncultivated sites (Hütsch et al., 1994).

Methane oxidation in the twice-ambient CO_2 treatment was on average 22% (range 2–61%) lower than

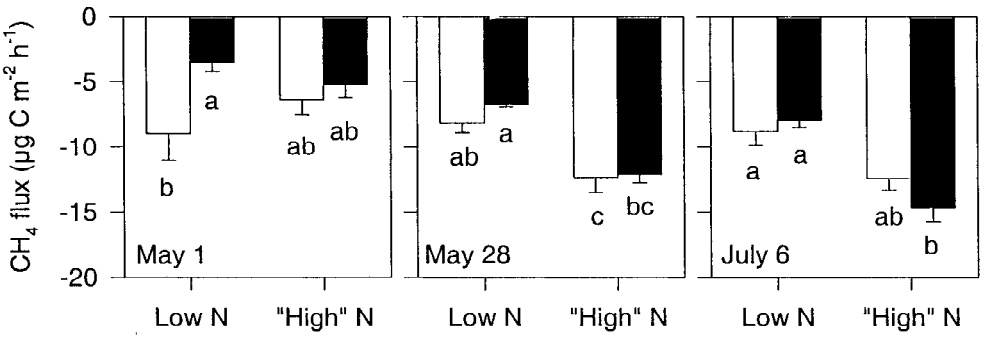

Figure 1. Fluxes of CH_4 from aspen (*Populus tremuloides*) stands grown in open top chambers under ambient (open bars) and twice-ambient (solid bars) CO_2 concentrations. Negative numbers indicate net CH_4 uptake. The CO_2 treatments were crossed with two soil N treatments. Numbers are means of five replicate chambers (±SE). Different letters indicate significant differences at each sampling time ($P<0.05$).

Table 2. Soil moisture and total inorganic N contents in soil from aspens (*Populus tremuloides*) grown under ambient CO_2 and twice-ambient CO_2 crossed with low N and 'high' N soil treatments. Numbers are mean of duplicate (±SE) aliquots of composite samples from five field replicates

GO_2 treatment	Date	% WFPS	Inorganic N (mg kg^{-1})
Low N soil			
Ambient	May 1	N.d.[a]	N.d.
	May 28	8.8[b]	0.9±0.03
	July 6	12.3±1.2	1.0±0.07
Twice-ambient	May 1	25.4±0.4	0.8±0.06
	May 28	10.7	1.1±0.04
	July 6	13.5±0.2	1.0±0.03
'High' N soil			
Ambient	May 1	45.1±0.03	3.6±0.1
	May 28	27.5	3.4±0.2
	July 6	14.5±0.5	2.7±0.02
Twice-ambient	May 1	46.1±0.5	3.9±0.3
	May 28	30.5	4.0±0.3
	July 6	15.8	2.9±0.1

[a]N.d.= no data; [b]one aliquot analyzed.

CH_4 oxidation in the ambient CO_2 treatment, excluding the 'high' N soil on July 6 (Figure 1). Averaging rates over sampling dates revealed a significantly ($P<0.05$) lower CH_4 oxidation in twice-ambient CO_2 plots (6.5±0.6 μg C m^{-2} h^{-1}) than in ambient CO_2 chambers (8.7±0.8 μg C m^{-2} h^{-1}) with low N soil. In the 'high' N soil CH_4 oxidation was not different between the two CO_2 treatments. Across dates and regardless of soil N treatment, twice-ambient CO_2 plots oxidized CH_4 at a rate of 8.8 μg C m^{-2} h^{-1} which is significantly lower than that for ambient CO_2 plots at 9.5 μg C m^{-2} h^{-1} ($P<0.05$; Mann Whitney non parametric statistics). Differences in CH_4 oxidation rates are coincident with trends in other soil parameters. First, the elevated CO_2 treatment tended to have higher soil water contents than the ambient CO_2 plots, on average 11% (Table 2). This is probably due to a higher water use efficiency of the aspens grown under elevated CO_2 (Owensby et al., 1993). Increased soil moisture constrains CH_4 diffusion and will therefore inhibit CH_4 oxidation (Dörr et al., 1993). Ineson et al. (1998) hypothesized that depressed CH_4 uptake in a ryegrass field in response to elevated CO_2 was caused by an increase in CH_4 production. A similar mechanism may also have been operative in our study. The importance of soil moisture in the temporal control of CH_4 uptake fluctuations was indicated by the significant negative correlations between the temporal variations in soil moisture and CH_4 uptake, viz. $r=-0.911$ ($n=6$; $P<0.05$) and $r=-0.915$ ($n=5$; $P<0.05$) for the low N and 'high' N soil, respectively. Secondly, inorganic N pools tended to be higher in the twice-ambient CO_2 plots than in the ambient CO_2 plots (Table 2). The differences, however, were very small, and would be unlikely to have the potential to depress CH_4 oxidation (Schnell and King, 1994). Moreover, the CO_2 treatments did not affect net- or gross N mineralization in the root boxes (Zak, 1998 – pers. comm.). Overall, this suggests that neither inorganic N pool sizes nor N tui nover was important for CH_4 turnover in this study.

Methane oxidation in laboratory-incubated soils occurred at constant rates during the 72 h incubation period (not shown). In Table 3 we report the oxidation rates calculated from linear regressions of CH_4 concentration vs. time. In incubations with 2 ppm CH_4, the CH_4 oxidation activity showed no response

Table 3. Rates of CH_4 oxidation (ng C kg^{-1} h^{-1}) in soil from aspen (*Populus tremuloides*) grown under ambient CO_2 and twice-ambient CO_2 crossed with low N and 'high' N soil treatments. The soil was incubated under 2 ppm CH_4 and under 100 ppm CH_4 in serum bottles. Numbers are means (±SE) of triplicate aliquots of composite samples from five field replicates; for each N treatment different letters indicate significant differences ($P<0.05$)

CO_2 treatment	2 ppm CH_4	2 ppm CH_4	100 ppm CH_4
Low N soil	May 1	May 28	
Ambient	N.d.[a]	22±lb	1650±334b
Twice-ambient	11±2a	17±2b	1274±96b
'High' N soil			
Ambient	54±8a	60±13a	3378±78a
Twice-ambient	71 ±6a	80±4a	2820±835a

[a] N.d.= no data

to the CO_2 treatment (Table 3). In incubations with 100 ppm CH_4 the data suggest that twice-ambient CO_2 depressed CH_4 uptake by 17 to 23%, in accordance with the results from the field chambers, but the variability among replicates was high and differences among CO_2 treatments were not significant. Evidently the mechanism responsible for depressed CH_4 uptake in response to enhanced CO_2 in the field was not operative in the incubated soil. This supports the finding discussed above that the reduced CH_4 oxidation *in situ* in the elevated CO_2 experiment was caused by lowered diffusion rather than changes in N availability; in incubated soil, aeration is much facilitated as compared with conditions *in situ*. On the other hand, differences in soil moisture was very small, and it can be debated whether they would be sufficient to influence the CH_4 oxidation. Nevertheless, Whalen et al. (1990) observed a 20-fold change in CH_4 oxidation when soil moisture changed from 5 to 11%, probably as a combination of changes in physical gas exhange and microbial water stress at the low moisture content (Adamsen and King, 1993).

Denitrification and nitrous oxide

Denitrification potentials were significantly enhanced by elevated CO_2 in the May 1 and July samples in the 'high' N soil (Figure 2). Phase I denitrification (existing enzyme activity; Smith and Tiedje, 1979) was increased 26% ($P<0.05$) by twice-ambient CO_2 on July 6. In contrast, on May 28, elevated CO_2 depressed Phase I denitrification by 39%; this difference, however, was only transient and not apparent after 48 h of incubation (Figure 2). Following 24 h (May 1) or 48 h (July 6) of incubation, the high N soil from twice-ambient CO_2 chambers had denitrified 19% and 11% more, respectively, than soil from ambient CO_2 chambers. In the low N soil, Phase I denitrification was similar for the two CO_2 levels. After 48 h of incubation on May 28, however, 21% more N was denitrified in soil from elevated CO_2 chambers than in soil from ambient CO_2 chambers.

From these data it can be concluded that the CO_2 treatments did not consistently affect concentrations of denitrifying enzymes whereas following prolonged exposure to denitrifying conditions denitrification was enhanced by the twice-ambient CO_2 treatment. As denitrifying organisms are dominated by heterotrophic bacteria (Tiedje, 1988), this increase may be due to increased substrate availability governed by increased below-ground C allocation by elevated-CO_2 aspens. Under denitrifying conditions, e.g. shortly after rain (Corre et al., 1995), soil N_2O fluxes may thus be greater from elevated CO_2 aspens than from ambient CO_2 aspens. However, the potential for such an effect in these sandy soils is limited (Groffman and Tiedje, 1989).

Both Phase I denitrification and denitrification after 24 or 48 h were significantly greater in the 'high' N soil than in the low N soil (Figure 2). This difference was also apparent for CH_4 oxidation activity in incubated soil (Table 3) and in chamber measurements on May 28 and July 6 (Figure 1), and may be ascribed to an overall greater microbial biomass in the 'high' N soil than in the low N soil. It is noteworthy, however, that phase I denitrification was 92-fold greater in the 'high' N soil than in the low N soil, whereas denitrification after 24 or 48 h was only 4.5-fold greater in the 'high' N soil. This suggests a higher potential for induction of denitrification in the low N soil than in the 'high' N soil.

Soil respiration was also determined in incubated soil samples and it was found that soil from twice-ambient CO_2 chambers on average had a 17% greater ($P<0.05$) activity than soil from ambient CO_2 chambers (Table 4); this calculation includes the non-significant differences on May 28 in 2 ppm CH_4 bottles. The often greater heterotrophic activity associated with soils from twice-ambient CO_2 chambers is in agreement with their increased denitrification potentials, which were probably fueled by increased below-ground C allocation by the elevated-CO_2 grown aspens. Among all data sets (n=3), respiration in the 'high' N soil was 5 times greater than in the low N soil,

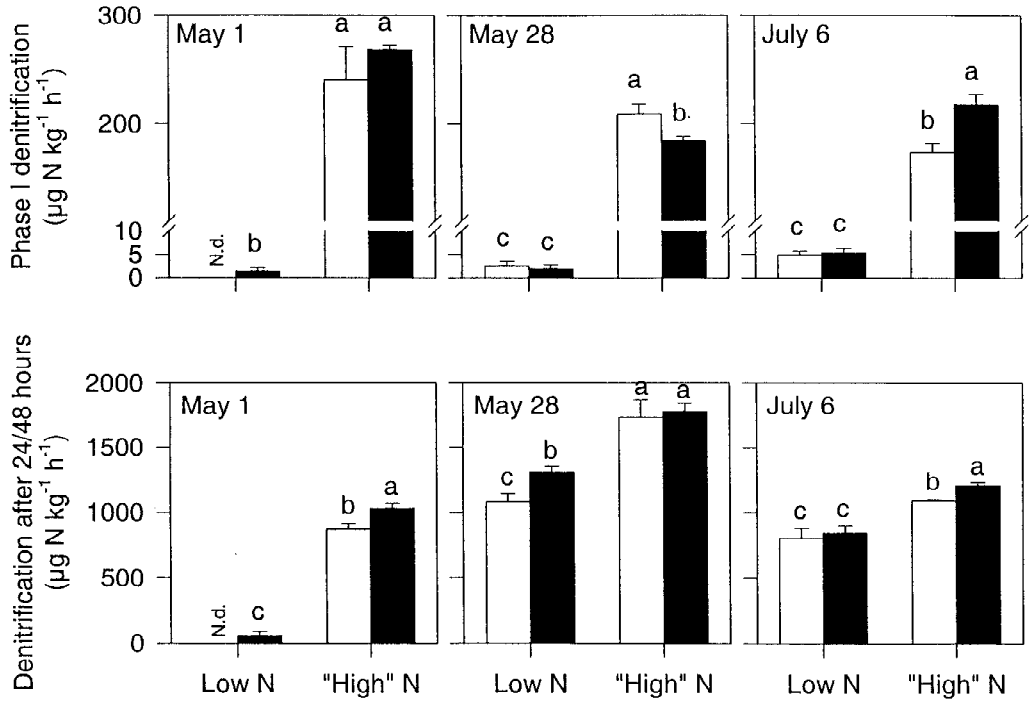

Figure 2. Denitrification potentials in soil samples taken from aspen (*Populus tremuloides*) stands grown in open top chambers under ambient (open bars) and twice- ambient (solid bars) CO_2 concentrations. The CO_2 treatments were crossed with two soil N treatments. Denitrification was measured regularly during 0-3 h of incubation, and again after 24 h (May 1) and 48 h (May 28 and July 6) of incubation. Numbers are means of triplicate aliquots (±SE) of a composite sample from five field replicates. Different letters indicate significant differences at each sampling time ($P<0.05$).

Table 4. Rates of CO_2 evolution (μg C kg^{-1} h^{-1}) in soil from aspen (*Populus tremuloides*) grown under ambient CO_2 and twice-ambient CO_2 crossed with low N and 'high' N soil treatments. The soil was incubated under 2 ppm (ambient) CH_4 and under 100 ppm CH_4 in serum bottles. Numbers are means (±SE) of triplicate aliquots of composite samples from five field replicates; for each N treatment different letters indicate significant differences ($P<0.05$)

CO_2 treatment	2 ppm CH_4	2 ppm CH_4	100 ppm CH_4
Low N soil	May 1	May 28	
Ambient	N.d.[a]	83±4b	75±0.4d
Twice-ambient	118±8c	83±lb	81±2c
'High' N soil			
Ambient	622±7b	338±8a	285±9b
Twice-ambient	743±6a	529±168a	352±0.5a

[a] N.d.= no data.

and is consistent with the differences in CH_4 oxidation and denitrification discussed above.

Fluxes of N_2O from the root boxes ranged between 0.1 and 2.1 μg N m^{-2} h^{-1} (Figure 3) and were similar to those obtained from poplar stands in Southwest Michigan (Robertson, 1997 – unpublished data) and from Massachusetts pine and hardwood stands (Bowden et al., 1990). Fluxes from replicate boxes, however, were variable and showed no consistent response to the CO_2 treatments. Likewise, N_2O fluxes did not differ among the N treatments except on May 28 when N_2O fluxes under twice- ambient CO_2 were 80 times greater from the 'high' N soil (2.5 μg N m^{-2} h^{-1}) than from the low N soil (0.03 μg N m^{-2} h^{-1}). In a recent study in a California grassland, Hungate et al. (1997) also observed unaltered N_2O emissions in response to CO_2 treatments whereas Ineson et al. (1998) and Arnone and Bohlen (1998) observed increased outputs of N_2O under elevated CO_2 in grass covered land.

Incubated cores without added inorganic N emitted N_2O at rates between 1.6 and 3.4 μg N m^{-2} h^{-1} (Figure 4). These rates are somewhat greater than those measured *in situ* in the open-top chambers in July when the cores were sampled (Figure 3), probably due to the wetting of the soil prior to incubation, but as

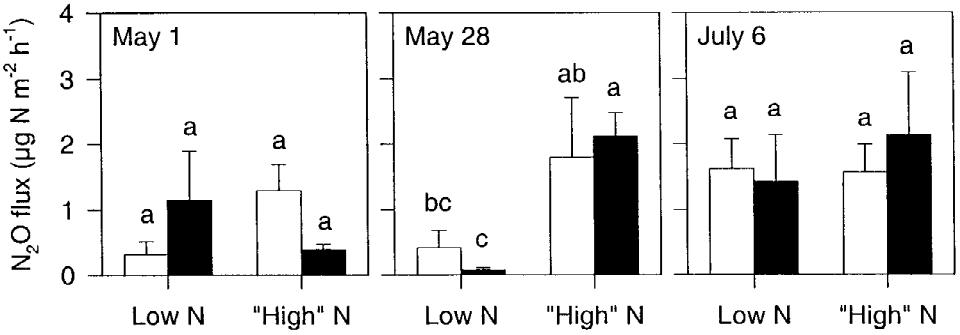

Figure 3. Fluxes of N_2O from aspen (*Populus tremuloides*) stands grown in open top chambers under ambient (open bars) and twice-ambient (solid bars) CO_2 concentrations. See caption for Figure 1.

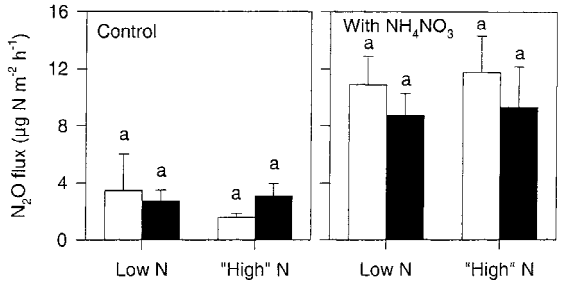

Figure 4. Fluxes of N_2O from incubated cores taken from aspen (*Populus tremuloides*) stands grown in open top chambers under ambient (open bars) and twice-ambient (solid bars) CO_2 concentrations. The CO_2 treatments were crossed with two soil N treatments. One set of cores was incubated with ambient inorganic N (control) and another set received additional N (NH_4NO_3) prior to incubation. Numbers are means of five replicate cores (±SE). Different letters indicate significant differences for each treatment ($P<0.05$).

with the field measurements (Figure 3) did not differ among CO_2 treatments nor *in situ* soil N treatments.

The N_2O fluxes in all treatments appeared to be limited by available N as fluxes in N-amended cores increased 3- to 4-fold (Figure 4). As for the unamended cores, N_2O fluxes from N-fertilized cores did not differ among CO_2 treatments or *in situ* soil N treatments. The similarity of the N_2O fluxes from the two *in situ* soil N treatments was unexpected, since both denitrification potentials (Figure 2) and total organic C (Table 1) were higher in the 'high' N soil than in the low N soil. Perhaps processes uncoupled from denitrification and C availability, i.e. autotrophic nitrification, were important for the N_2O formation under the prevailing field conditions. In the root boxes, WFPS did not exceed 46% (Table 2) and in the laboratory-incubated cores soil moisture was equivalent to 41% and 39% WFPS for low N and 'high' N soil, respectively. These soil moisture values are all less than 60% WFPS, below which denitrification N_2O production is likely to be negligible (Davidson, 1991; Linn and Doran, 1984).

Conclusions

We found evidence for depressed CH_4 oxidation by soil in aspen stands grown under elevated CO_2 conditions compared with aspens under ambient CO_2 conditions. As such, the anticipated global increase in atmospheric CO_2 may have a negative feedback on the terrestrial CH_4 cycle, increasing CH_4 emissions from upland soil indirectly by inhibiting CH_4 oxidation. In contrast, N_2O fluxes were identical under the different CO_2 conditions. However, we found evidence for temporal greater denitrification in the soil from twice-ambient CO_2 aspens than in soil from the ambient-CO_2 aspens. Denitrification conditions did not apply in our field study, but it can be speculated that induction of denitrification conditions e.g. by rain events may lead to greater N_2O fluxes from elevated-CO_2 aspens than from ambient-CO_2 aspens. This needs further investigation.

Our results suggest that increased atmospheric CO_2 may induce global warming to a stronger degree than current estimates because changes in soil conditions may ultimately lead to depressed oxidation of atmospheric CH_4 in upland soils.

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