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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Soil-atmosphere exchange of CH_4, CO_2, NO_x, and N_2O in the Colorado Shortgrass Steppe following five years of elevated CO_2 and N fertilization" *by* A. R. Mosier et al.

A. R. Mosier et al.

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Response to Anonymous Referee #1: From A.R. Mosier

The reviewer has some good suggestions for improving the manuscript. Following is response to each comment:

1. Title change: Effect of water addition and nitrogen fertilization on the fluxes of CH4, CO2, NOx, and N2O following five years of elevated CO2 in the Colorado Shortgrass Steppe

2. Introduction and Discussion have been modified. See response to specific comments.

3. Specific Comments:

Abstract has been modified to: Abstract. An open-top-chamber (OTC) CO_2 enrichment (˜720 ?mol mol-1) study was conducted in the Colorado shortgrass steppe from April 1997 through October 2001. Aboveground plant biomass increased under elevated CO_2 and soil moisture content was typically higher than under ambient CO_2 conditions. Fluxes of CH_4, CO_2, NO_x and N_2O, measured weekly year round were not significantly altered by CO_2 enrichment over the 55 month period of observation. During early summer of 2002, following the removal of the open-top-chambers from the CO_2 enrichment sites in October 2001, we conducted a short term study to determine if soil microbial processes were altered in soils that had been exposed to double ambient CO_2 concentrations during the growing season for the past five years. Microplots were established within each experimental site and 10 mm of water or 10 mm of water containing the equivalent of 10 g m-2 of ammonium nitrate-N was applied to the soil surface. Fluxes of CO_2, CH_4, NO_x and N_2O fluxes within control (unchambered), ambient CO_2 and elevated CO_2 OTCs soils were measured at one to three day intervals for the next month. With water addition alone, CO_2 and NO emission did not differ between ambient and elevated CO_2 soils, while CH_4 uptake rates were higher and N_2O fluxes lower in elevated CO_2 soils. Adding water and mineral N resulted in increased CO_2 emissions, increased CH_4 uptake and decreased NO emissions in elevated CO_2 soils. The N addition study confirmed previous observations that soil respiration is enhanced under elevated CO_2 and N immobilization is increased, thereby decreasing NO emission.

Introduction has been modified:

Introduction

During the past few decades the atmospheric concentration of CO_2 has increased at historically unprecedented rates, as have N_2O and CH_4 concentrations (IPCC, 2001). Increasing CO_2 concentrations will have a direct effect on plant production and plant

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communities and indirectly feed back into a number of soil biotic systems that influence long term ecosystem viability (Hungate et al. 1997a,b,c; Owensby et al. 1993a). The impact of elevated CO_2 on the shortgrass steppe, which is used extensively for grazing and is similar to regions which occupy about 8 % of the U.S. and about 11% of global land area (Bailey, 1979) has not been previously addressed. These interactive feedbacks on the soil C and N cycles and their influence on trace gas fluxes have potentially important impacts on the global atmospheric budgets of the gases and the long term sustainability of the grassland. Earlier studies within the shortgrass steppe have demonstrated that such grasslands play an important role as consumers of atmospheric CH_4, and producers of N_2O (Mosier et al. 1991; 1996; 1997). Doubling CO_2 had little impact on trace gas fluxes in the shortgrass steppe (Morgan et al. 2001; Mosier et al. 2002a). The few measurements of NO_x, N_2O, CH_4 and CO_2 fluxes in CO_2 enrichment studies in other ecosystems have given contradictory results. Growth chamber studies suggest that plant C/N ratios, nitrogen use efficiency and water use efficiency all increase under elevated CO_2 (Drake et al. 1996; Morgan et al. 1994; Rogers et al. 1994). In the short term, increases in soil moisture content resulting from higher water use efficiency (Hungate et al. 1997a,b,c) may accelerate rates of C and N mineralization , increasing N availability for plant uptake. Over the long term, however, decreased litter quality is expected to increase N immobilization rates and reduce N availability for plant uptake. From these observations we hypothesized that initially elevated CO_2 would induce increased soil moisture and increased N mineralization rates (Hunt et al. 1988). As a result, CO_2, NO and N_2O emissions should increase on the short term under elevated CO_2 , while CH_4 uptake should decrease. Over the longer term, however, increased C/N ratios in plant litter and roots would result in longer term decreases in N mineralization rates, and decreased NO and N_2O fluxes would be observed. To test these responses, Mosier et al. (2002a) monitored the soil-atmosphere exchange of CO_2, NO_x, N_2O and CH_4 weekly, year-round, April 1997 to November 2001 on unchambered control, ambient CO_2 and ˜720 ?mol mol-1 CO_2 experimental plots in the Colorado shortgrass steppe. Mosier et al. (2002a; 2002b) observed no

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statistically significant CO_2 enrichment effect on ecosystem respiration, oxidation of atmospheric CH_4, or emissions of NOx or N_2O. Methane oxidation tended to be higher under elevated CO_2 while NOx and N_2O tended to be lower, but not significantly in either case. Above ground biomass production was higher under elevated CO_2 (Morgan et al. 2001), which utilized more soil N (King et al. 2003). However, soil N mineralization was probably enhanced under elevated CO_2 because of more moist soils (Hungate et al. 1997a,b,c). The two opposing processes apparently offset each other because NOx and N_2O emissions, which reflect system N mineralization and nitrification, did not differ. Ecosystem respiration, which included soil and aboveground plant respiration, was not generally higher under elevated CO_2 (Mosier et al. 2002a). During the 5 years of the study trace gas exchange measurements suggested that soil microbial processes were not greatly altered under double CO_2 concentrations, at least in the short term. Plant production during a year of above average rainfall did, however, appear to be limited by N availability (King et al. 2003). By analyzing the concentration of soil CO_2 at different depths in the OTCs and calculating soil respiration, Pendall et al. (2003) and found that elevated CO_2 increased soil respiration by about 25% in a moist growing season and by about 85% in a dry season. Significant increases in soil respiration rates occurred only during dry periods. ?13C analyses of soil CO_2 revealed that soil organic matter decomposition rates were more than doubled under elevated CO_2 whereas rhizosphere respiration rates were not changed. Estimates of net ecosystem production, which account for both inputs and losses of carbon, suggest that soil carbon sequestration is not increased under elevated CO_2 during dry years, but may be in wet years (Pendall et al., in review). We were interested to determine if residual effects on microbial processes persisted following CO_2 enrichment. During early summer of the year following the removal of the open-top chambers from the CO_2 enrichment sites we conducted a short term study to determine if soil microbial processes were altered in soils that had been exposed to double ambient CO_2 concentrations during the growing season for the past five years. The response of emissions of CO_2, NOx and N_2O and the uptake of atmospheric CH_4 to water addition and water and mineral nitrogen fertilization to soils that had or had not been exposed to elevated CO2 are reported in this paper.

Materials and methods Pg 2695 section 2.1. No changes were made in Table 1 because after 5 years under elevated CO2 the soil total C and total N content did not change detectably from the beginning of the study. Also, soil water holding characteristics did not change. Soil moisture content was the same in all experimental plots at the start of the water/N addition study.

Results section

Pg 2698, line 15, section 3.1 has been modified to: Trace Gas Fluxes. During the five year study prior to the N-addition experiment NOx flux averaged 4.3 in ambient and 4.1 ?g N m-2 hr-1in elevated chambers . NOx flux was negatively correlated to plant biomass production. Nitrous oxide emission rates averaged 1.8 and 1.7 μg N m-2 hr-1, CH4 flux rates averaged -31 and -34 ?g C m-2hr-1 and ecosystem respiration averaged 43 and 44 mg C m-2hr-1 under ambient and elevated CO2, respectively, over the same time period (Mosier et al. 2002a, b). We conducted the short-term N-addition to see if any residual effects of elevated CO2 remained during the growing season following the five years of CO2 fumigation and found that some important changes in soil microbial responses resulting from CO2 enrichment.

Pg2698 line 10, pg 2698 line 12; section changed to:

NO and N2O Emissions. NO emissions from the control soils were higher than from soils that had been under ambient or CO2 enriched chambers when the soils were irrigated (Table 2). This response was similar to the long term NO fluxes observed where control soil NO emissions averaged 11 μg m-2 hr-1 compared to 4.3 and 4.1 in ambient and CO2 enriched chambers (Mosier et al. 2002a). Plant production and uptake of nitrogen was opposite this trend with plant biomass being greater under elevated CO2 $>$ambient CO2$>$unchambered control (Morgan et al. 2001). This suggests that N availability for NO production by nitrifiers is partly regulated by plant uptake (Mosier

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et al. 2002a). Nitrous oxide emissions were significantly lower ($P<0.05$) from soils that had been exposed to elevated CO2 (Table 2). This may also reflect the lower N availability to soil microbes under elevated CO2 due to enhanced plant production (King et al. 2003). Both N2O and to a lesser extent NO emissions increased following water application (Fig. 1 a & b). Over the measurement period when water alone was added, NO/N2O ratios ranged between 2 and 5 with the highest in the elevated CO2 soils. When NH4NO3 was added N2O flux tripled in elevated CO2 soils ($P<0.05$), and increased slightly in control and ambient chamber soils ($P>0.05$). NO emissions and N2O emissions in N-fertilized soils increased markedly following each irrigation and precipitation event (Figs. 1 a, b, & e). Nitric oxide fluxes increased almost 10 fold with N addition in control and ambient CO2 soils but only about 5-fold in elevated CO2 soils. NO emissions were significantly lower from elevated CO2 soils than from control or ambient CO2 soils, again indicating the lower availability of N in the elevated CO2 soils. Hungate et al. (1997 b,c) found that, during wet up, NO emissions were depressed by 55% in high nutrient conditions under elevated CO2 (ambient + 360 ?mol mol-1) while there was no difference among treatments in N2O emissions. They attributed the decreased NO emissions under elevated CO2 to increased N immobilization. Increased utilization of added N by soil microbes, thus a decrease in NO emissions, appears to be the case in this study as well (Table 2).

Pg 2699 line 26, pg 2700 line 1: section changed to:

CO2 and CH4 Fluxes. Plant growth during the time of the study was virtually nonexistant because of the very low amount of precipitation that had fallen in the preceding year. Ecosystem CO2 flux (dark chamber respiration which includes plant, root and soil microbial respiration) increases following water addition were similar in all soils (Fig. 1d; Table 2). Only with water + N addition did CO2 fluxes from elevated CO2 soils exceed those from control and ambient soils ($P<0.05$). Microbial respiration appears to be enhanced under elevated CO2 (Pendall et al., 2003), especially when microbes are not limited by water or N availability. N addition appeared to stimulate soil microbial res-

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piration while decreasing NO emissions because of increased microbial immobilization of added N. Hu et al. (2001) suggest that over the long term, soil microbial decomposition is slowed under elevated CO_2 because of N limitation. The rate of uptake of atmospheric CH_4 was significantly greater ($P<0.05$) in elevated CO_2 soils than either control or ambient CO_2 soils (Fig. 1c; Table 2). CH_4 uptake rates were not measurably enhanced with N addition in control or ambient CO_2 soils but tended to be greater in elevated CO_2 soils ($P>0.05$). During the 5-years of CO_2 enrichment CH_4 uptake rates tended to be higher under elevated CO_2. This short term study suggests that a microbial population developed under elevated CO_2 which tended to increase utilization of atmospheric CH_4. Ineson et al. (1998) observed lower CH_4 uptake rates under elevated CO_2 within a free-atmosphere CO_2-enrichment (FACE) study in Switzerland. They also observed lower CO_2 respiration rates and increased N_2O emissions under elevated CO_2. McLain et al. (2002) also observed lower CH_4 consumption rates under elevated CO_2 in a pine plantation. The decrease in CH_4 consumption was attributed, in part to wetter soils under elevated CO_2. Soil conditions in the pine forest were likely much more comparable to the grassland soils in Switzerland (Ineson et al. 1998) than to the much drier conditions in the Colorado shortgrass steppe. The wetter soil conditions under elevated CO_2 in the Colorado grassland (Ferretti et al. 2003) likely produced more favorable conditions for methanotrophic activity, rather than limiting CH_4 diffusion into the soil in the Swiss grassland (Ineson et al. 1998) and the pine forest (McLain et al. 2002).

Technical Corrections have been made in text

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