Title
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Effect of CH₄ and O₂ variations on rates of CH₄ oxidation and stable isotope fractionation in tropical rain forest soils

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Abstract

Methane-utilizing bacteria are the primary sink for CH₄ in reduced soils, and account for as much as 96% of all CH₄ produced. Methanotrophic bacteria strongly discriminate against the heavy isotope of carbon, resulting in CH₄ oxidation that is not significantly more enriched in ¹³C than the original source material. Previous studies have shown an isotope mass balance approach to quantify CH₄ sources and sinks in the field based on the assumption that the fractionation factor for CH₄ oxidation is a constant. This study quantifies the effect of systematic variations in CH₄ and O₂ concentrations on rates of CH₄ oxidation and stable isotope fractionation in tropical rain forest soils. Soils were collected from the 0-10 cm depth, incubated with varying concentrations of CH₄ (100 ppmv, 500 ppmv, and 1000 ppmv) and 100 ppmv O₂, and CH₄ and O₂ treatments showing similar rates of CH₄ uptake. Rates of CH₄ oxidation did not vary significantly between the different O₂ treatments. The fractionation factor for CH₄ oxidation varied significantly between the different CH₄ treatments, with the 100 ppmv CH₄ treatment showing the lowest rate of CH₄ uptake, and the other 2 treatments showing similar rates of CH₄ uptake. Rates of CH₄ oxidation did not vary significantly between the different CH₄ treatments. The isotope fractionation factor for CH₄ oxidation was calculated for each incubation using a Redfield fractionation model. Rates of CH₄ oxidation varied significantly between CH₄ treatments, with the 100 ppmv CH₄ treatment showing the lowest rate of CH₄ uptake, and the other 2 treatments showing similar rates of CH₄ uptake. Rates of CH₄ oxidation did not vary significantly between the different O₂ treatments. The fractionation factor for CH₄ oxidation varied significantly between the different CH₄ treatments, with the 100 ppmv CH₄ treatment showing the lowest rate of CH₄ uptake, and the other 2 treatments showing similar rates of CH₄ uptake. Rates of CH₄ oxidation did not vary significantly between the different O₂ treatments. These results challenge the assumption that the isotope fractionation factor for CH₄ oxidation remains constant, regardless of in situ activity or CH₄ pool size.

Introduction

Upland tropical forests are generally considered an ozone sink for atmospheric CH₄ (Keller & Matson 1994), though recent research suggests that tropical rainforests are a net source of CH₄ when warmed (Figure 1; also Silver et al. 1999). The factors that regulate CH₄ emissions that are significantly more enriched in ¹³C than the original source material. Previous studies have shown an isotope mass balance approach to quantify CH₄ sources and sinks in the field based on the assumption that the fractionation factor for CH₄ oxidation is a constant. This study quantifies the effect of systematic variations in CH₄ and O₂ concentrations on rates of CH₄ oxidation and stable isotope fractionation in tropical rain forest soils. Soils were collected from the 0-10 cm depth, incubated with varying concentrations of CH₄ (100 ppmv, 500 ppmv, and 1000 ppmv) and 100 ppmv O₂, and CH₄ and O₂ treatments showing similar rates of CH₄ uptake. Rates of CH₄ oxidation did not vary significantly between the different O₂ treatments. The fractionation factor for CH₄ oxidation varied significantly between the different CH₄ treatments, with the 100 ppmv CH₄ treatment showing the lowest rate of CH₄ uptake, and the other 2 treatments showing similar rates of CH₄ uptake. Rates of CH₄ oxidation did not vary significantly between the different O₂ treatments. These results challenge the assumption that the isotope fractionation factor for CH₄ oxidation remains constant, regardless of in situ activity or CH₄ pool size.

Results I

• Rates of CH₄ oxidation varied significantly between CH₄ treatments (ANOVA, P = 0.0005; see Figure 2), with the 100 ppmv CH₄ treatment showing the lowest rate of CH₄ uptake (Fisher LSD, P < 0.05).
• Rates of CH₄ oxidation did not vary significantly between the different O₂ treatments (Figure 5).

Results II

• The isotope fractionation factor (εCH₄=εCH₄) for CH₄ oxidation varied significantly between CH₄ treatments at the 0.010 level (ANOVA, P = 0.005, see Table 1). The fractionation factor for CH₄ oxidation was greater in the 100 ppmv CH₄ treatment than in the 100 ppmv CH₄, 500 ppmv CH₄ (Fisher’s LSD, P < 0.05).
• Initial CH₄ concentrations were positively correlated with εCH₄ (P < 0.04, r² = 0.24, see Figure 4). Rates of CH₄ oxidation were negatively correlated with εCH₄ (P < 0.05, r² = 0.33; see Figure 3).
• A multiple regression model that included initial CH₄ concentration and CH₄ oxidation rate as independent variables accounted for 94% of the variability in the isotope fractionation data, suggesting that both factors are important in determining the extent of isotope fractionation (P < 0.04, r² = 1.0).
• The fractionation factor for CH₄ oxidation did not vary significantly between the different CH₄ treatments. These results challenge the assumption that the isotope fractionation factor for CH₄ oxidation remains constant, regardless of in situ activity or CH₄ pool size.

Conclusions

• The isotope fractionation factor (εCH₄=εCH₄) for CH₄ oxidation was not constant.
• The degree of isotope fractionation was best predicted by the rate of the process (methanotrophic biomass) and by the initial concentration of substrate.
• Isotope mass balance models cannot be quantitatively applied without knowledge of the total activity of the methanotrophic population.

Acknowledgments

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References


Figure 2. CH₄ oxidation rate for different initial CH₄ concentrations at 21°C ( date range represented mean values and error bars represent standard errors. )

Figure 3. CH₄ oxidation rate for different initial CH₄ concentrations and different initial O₂ concentrations at 21°C ( date range represented mean values and error bars represent standard errors. )

Figure 4. Regression of the isotope fractionation factor for CH₄ oxidation on the concentration of CH₄ oxidation rate and substrate CH₄ concentration (P = 0.0003, r² = 0.86).

Figure 5. Regression of the isotope fractionation factor for CH₄ oxidation on the concentration of CH₄ oxidation rate and substrate CH₄ concentration (P = 0.0003, r² = 0.06).

Table 1. Isotope fractionation factor for CH₄ oxidation in different CH₄ treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 ppmv</td>
<td>1.0173</td>
</tr>
<tr>
<td>500 ppmv</td>
<td>1.0212</td>
</tr>
<tr>
<td>1000 ppmv</td>
<td>1.0225</td>
</tr>
</tbody>
</table>

Means were compared using Fisher’s LSD test, followed by an error term, and the symbol “A” indicates significant difference.