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Influence of elevated concentrations of atmospheric CO_2 on CH_4 and CO_2 entrapped in rice-paddy soil

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Abstract

Controlled environment chambers were used to study the influence of elevated atmospheric CO_2 concentration on CH_4 and CO_2 entrapped in soil bubbles and in solution in rice-paddy soil. Throughout the growing season, CO_2 concentration was maintained at 383 ± 11 μmol mol^{-1} during the day and 446 ± 40 μmol mol^{-1} at night for ambient CO_2 treatment, and at 706 ± 13 μmol mol^{-1} (day) and 780 ± 76 μmol mol^{-1} (night) for the elevated CO_2 treatment. At the grain-filling stage of growth, rice plants in the chambers were supplied with ^{13}C-enriched CO_2 ($\delta^{13}C = 413.9$‰) for 3 days to study the allocation and transformation of photosynthetic carbon to root biomass, water-soluble organic carbon (WSOC) in soil solution, and CO_2 and CH_4 entrapped in the soil. Elevated atmospheric CO_2 concentration not only directly increased the biomass above ground and in the roots by photosynthesis, but also indirectly increased the amounts of CH_4 and CO_2 entrapped in the soil. Most of the CO_2 was dissolved in soil solution, but in contrast most of the CH_4 existed in soil bubbles. When rice was fed with ^{13}C-enriched CO_2 at the grain-filling stage of growth, the increase in ^{13}C of entrapped CO_2 under ambient CO_2 conditions accounted for 1.476% of the increase in ^{13}C of the rice plants and for 1.845% of the increase in ^{13}C of rice plants grown under elevated CO_2 conditions. The increase in ^{13}C of entrapped CH_4 accounted for 0.178% and 0.234% of the increase in ^{13}C of rice plants grown under ambient and elevated CO_2 treatments, respectively. Under conditions of elevated CO_2 the entrapped ^{13}C–CO_2 and ^{13}C–CH_4 increased by 57% and 65%, respectively. The increase in ^{13}C after feeding with ^{13}C-enriched CO_2, as a proportion of the total C of plants before feeding, was higher for CH_4 entrapped in rice-paddy soil than for CO_2 entrapped in rice-paddy soil, WSOC in soil solution, aboveground biomass, and root biomass under both ambient and elevated CO_2 treatments. This indicates that during the grain-filling stage of rice growth, photosynthesized carbon had the most impact on CH_4 production and accelerated the CH_4 turnover rate.

Keywords: Bubble; Carbon dioxide (CO_2); Isotope; Methane (CH_4); Rice; Soil solution

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1. Introduction

Recent anthropogenic emissions of key atmospheric trace gases (the so-called greenhouse gases, e.g., CO_2, CH_4, N_2O, and CFCs) that absorb infrared radiation may lead to an increase in global mean surface temperature, subsequent changes in climate (IPCC, 1995). Long-term records demonstrate a steady rise in atmospheric CO_2 since the pre-industrial era, with an accelerated rate of rise in recent decades (Houghton et al., 1990), and it is thought that the concentration of CO_2 in the atmosphere may double by the middle of the 21st century (Bolin, 1986). After CO_2, methane (CH_4) is the most important greenhouse gas, responsible for approximately 20% of the anthropogenic global warming effect. The concentration of atmospheric CH_4 increased from 0.75 to 1.73 μmol mol^{-1} during the past 150 years (Lelieveld et al., 1998). It was increasing at about 1% per year (Crutzen, 1991), although the rate of increase of CH_4 has declined (Dlugokencky et al., 1998).

Most atmospheric CH_4 is produced by microbial activity in extremely anaerobic ecosystems, such as natural and cultivated wetlands, sediments, sewage, landfills, and the guts of ruminants animals. Methane from rice paddies accounts for about 17% of the total anthropogenic sources (IPCC, 1995). In rice-paddy soil, acetate and H_2–CO_2 are the major substrates for CH_4 production (Takai, 1970), and plant-mediated transport is a very important pathway for CH_4 emission from the soil (Inubushi et al., 1989; Schutz et al., 1989; Nouchi et al., 1990; Wassmann et al., 1996).

Many studies have demonstrated that elevated concentrations of CO_2 have a positive effect on rice biomass production (above and below ground) and on grain yield (Baker and Allen, 1993; Ziska et al., 1997; Sakai et al., 2001; Kim et al., 2001, 2003). Elevated CO_2 also increases soil microbial C and accelerates the turnover rate of soil organic C during the middle and later stages of the rice development (Cheng et al., 2001; Hoque et al., 2001). The direct effect of elevated CO_2 on rice root biomass and tiller number can potentially increase CH_4 emission from rice fields by 50%–60% (Ziska et al., 1998; Inubushi et al., 2003). The roots of rice plants grown under CO_2-enriched conditions may also enhance CH_4 production directly by providing carbon substrates in the form of root exudates or root autolysis products, which are easily decomposed by fermentative bacteria to CO_2, H_2, and acetate, which are then utilized by methanogens (Minoda et al., 1996).

Except for N_2, CH_4 and CO_2 are the two main constituents of the gas found in flooded rice-paddy soil. Because CH_4 is less soluble than CO_2 in water, most of the CH_4 produced is entrapped as bubbles in flooded rice-paddy soil (Uzaki et al., 1991; Chidthaisong and Watanabe, 1997). Entrapped CH_4 in flooded rice-paddy soil could be (1) oxidized to CO_2 in the rice rhizosphere and the floodwater–soil interface as it diffuses upwards; (2) released by ebullition (bubbles); or (3) emitted to the atmosphere through the rice plant. Studying CH_4 entrapped in soil bubbles is useful for understanding how CH_4 is produced, oxidized, and emitted to the atmosphere. Ziska et al. (1998) found that the amounts of CH_4 emitted from tropical rice paddies were consistent with changes in the amounts of dissolved CH_4. A comparison between the amounts of CH_4 entrapped in rice-paddy soil bubbles and the amounts of CH_4 dissolved in soil solution is, therefore, important to our understanding of CH_4 dynamics.

A few studies have used ^{13}C or ^{14}C pulse-labeling experiments to examine the contribution of photosynthates to CH_4 production and emission in rice paddies and wetlands (Minoda et al., 1996; King and Reeburgh, 2002). However, there are no reports of how increased atmospheric CO_2 concentration influences the contribution of photosynthates to CH_4 and CO_2 production in rice-paddy soil. Here we report the results of a ^{13}C pulse-labeling experiment conducted under controlled environmental conditions to evaluate the effects of elevated concentrations of atmospheric CO_2 on CH_4 and CO_2 dynamics in rice-paddy soil by measuring $\delta^{13}C$ and the amounts of CO_2 and CH_4 entrapped in both soil bubbles and soil solution.

2. Materials and methods

2.1. Controlled environment chambers and experimental design

This research was conducted at National Institute for Agro-Environmental Sciences (NIAES), Tsukuba, Japan in a growth chamber system (Climatron;