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Effects of elevated temperature and atmospheric carbon dioxide concentration on the emissions of methane and nitrous oxide from Portuguese flooded rice fields

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HIGHLIGHTS

- CH_4 emissions numerically increased by 50% with elevated temperature and $[CO_2]$.
- N_2O emissions were not affected by temperature and $[CO_2]$ relative to open-field.
- Default seasonal CH_4 EF for Portuguese flooded rice fields was 10.0 g m^{-2}.
- Default seasonal N_2O–N EF for Portuguese flooded rice fields was 1.4% of N input.

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ABSTRACT

Methane (CH_4) and nitrous oxide (N_2O) emissions from flooded rice fields have been rarely measured in Europe. A field study was carried out in an intermittent flooded rice field at central Portugal to investigate if global warming under Mediterranean conditions, elevated soil temperature (+2 °C) and atmospheric $[CO_2]$ (550 ppm), could lead to significant effects in CH_4 and N_2O emissions. The experimental design consisted of three treatments arranged in a randomized complete block design with three replicates. To assess the effects of ambient temperature and actual atmospheric $[CO_2]$ (375 ppm), plots were laid under open-field rice conditions. Using open-top chambers, two other treatments were established: one to assess the effect of elevated temperature and actual atmospheric $[CO_2]$ and a third treatment to evaluate the combined effect of elevated temperature and atmospheric $[CO_2]$. Measurements of CH_4 and N_2O fluxes were made throughout two consecutive growing seasons in the field using the closed chamber technique. Elevation of temperature with or without elevated atmospheric $[CO_2]$ increased CH_4 emissions by 50%, but this increase was not significant compared to the open-field condition. As for N_2O, elevated temperature alone or combined with elevated atmospheric $[CO_2]$ had no significant effect on emissions relative to the open-field treatment. The estimated seasonal CH_4 EF for the Portuguese flooded rice fields was 10.0 g CH_4 m^{-2}, while the EF for N_2O emissions was 1.4% of N input. These results suggested that default seasonal CH_4 and N_2O EFs currently used by the Portuguese inventory were not appropriated.

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1. Introduction

Portugal is the fourth European rice producer (5.3% of the total European production) with 28,000 ha of cultivated area, mostly under intensive cultivation with flooded conditions and only one growing season per year (May to October). Like in almost all Mediterranean countries, no emission factors (EFs) for flooded rice are available. Flooded rice fields are a major source of greenhouse gases (GHGs) emission to the atmosphere, contributing with 10.0–36.0 g methane (CH_4) m^{-2} season (IPCC, 2006) and an average of 0.3% of nitrogen (N) input as nitrous oxide (N_2O) (Akiyama et al., 2005; IPCC, 2006). These two GHGs are responsible for global warming and N_2O also contributes to the destruction of the ozone layer (IPCC, 2007).

Methane in flooded rice fields is originated from anaerobic conditions and is emitted through soil layers by ebullition and diffusion, through floodwater, and through the aerenchyma of the plants (Aulakh et al., 2001a; Le Mer and Roger, 2001). Nitrous oxide is produced by chemolithoautotrophic ammonium-oxidizing bacteria through nitrification-denitrification process, as well as by heterotrophic denitrifiers, in presence of ammonium (NH_4^+), nitrate (NO_3^-) and decomposable organic carbon (C) at locally and temporarily restricted oxygen supply (Granli and Bøckmann, 1994; Aulakh et al., 2001b). In particular, agronomic management practices, but also the climatic parameters are key factors that control CH_4 and N_2O emissions (Nue et al., 1996; Yadvinder-Singh et al., 2005; Dong et al., 2011; Cai et al., 2013; Datta et al., 2013).

Environmental consequences that could lead to climate change resulted in the elaboration of several international legislations (e.g. National Emissions Ceilings for 2020) designed to report estimates of GHGs from each country on an annual basis, in order to develop a strategy for meeting the agreed targets. To accomplish this, specific EFs are needed for inclusion in National Inventories.

Considering projected climate change scenarios, the atmospheric carbon dioxide concentration ([CO_2]) is expected to increase from the actual concentration (280–380 ppm) to 700–1000 ppm by 2100 (IPCC, 2007). Also expected is an increase of global air temperature between 1.8 and 4.0 °C due GHG emissions from anthropogenic sources (IPCC, 2007). In theory, an increase of air temperature and atmospheric [CO_2] will lead to an increase in crop yield, soil microbial activity and consequently CH_4 and N_2O emissions (Aulakh et al., 2001a; Wrage et al., 2001; Cheng et al., 2006; Kammann et al., 2008). In practice, contradictory results have been obtained about the effects of elevated temperature and/or [CO_2] on these parameters (Ziska et al., 1998; Cheng et al., 2006; Tokida et al., 2010; Xie et al., 2012; Yun et al., 2012). In general, on a worldwide basis and in particular for European conditions a limited number of studies aiming to address the effects of climate change (temperature and [CO_2]) on default EFs for CH_4 and N_2O emissions from flooded rice fields have been published.

The objectives of our study were to investigate if, under global warming, elevated soil temperature (+2 °C) and atmospheric [CO_2] (550 ppm) could lead to significant differences in CH_4 and N_2O emissions from flooded rice fields in Mediterranean conditions.

2. Materials and methods

2.1. Site description

The rice field experiment was conducted during two consecutive seasons (2011 and 2012) at the experimental farm COTArroz located at Salvaterra de Magos (central Portugal, latitude: 39°2.2015′N, longitude: 8°44.257′W, elevation: 18 m above mean sea level), and integrated in the water irrigation infra-structure of Sorraia and Tejo Valleys. This study area is the main region for rice production in Portugal where intermittent waterlogged rice has been cultivated from May to October since the beginning of the 18th century. Such region has a Mediterranean climate influence with a mean annual precipitation of about 650 mm (75% rainfall between October and March), and mean annual air temperature of about 9.5 °C and 21.3 °C in the coldest (January) and in the warmest (August) months, respectively.

The soil of the experimental field is classified as Anthrosols (classification of the World Reference Base for Soil Resources 2006) which has a clay loam texture (197 g kg^{-1} sand, 269 g kg^{-1} silt and 534 g kg^{-1} clay). The main physic-chemical characteristics of the topsoil (0–20 cm) are the following ones: bulk density, 1.1 g cm^{-3}; $pH_{H_2O} = 5.8$; total organic C, 24.6 g kg^{-1}; total N, 2.4 g kg^{-1}. Most soils of the Portuguese rice production areas had similar physic-chemical characteristics of the experimental field of the present study.

2.2. Experimental design

The experimental design consisted of three treatments arranged in a randomized complete block design (RCBD) with three replicates: a treatment to assess the effects of ambient air temperature and actual atmospheric [CO_2] (375 ppm), was laid under open-field rice conditions (treatment: Open-field); a treatment was included to assess the effects of elevated air temperature and actual atmospheric [CO_2] (375 ppm) (treatment: Temperature), and; a third treatment to evaluate the combined effect of elevated air temperature and atmospheric [CO_2] (550 ppm) (treatment: Temperature + CO_2). The Temperature and Temperature + CO_2 treatments were established using open-top chambers (OTCs) as described in detail by De Costa et al. (2006). Six OTCs (4 m diameter, 2.5 m height, 2 m diameter open-top) were constructed with an octagonal galvanized steel structure (1.55 m length, 2.50 m height) made with steel tubes (30 mm external diameter) and fitted together with kit connections. In the top of each structure, the vertical beams of the structure were bent inwards to have a tapered open-top of 2 m diameter and 30° tilt. Also, on one side of each OTC, a door (0.75 m length and 2.5 m height) was inserted to allow access to the inside, but was kept closed during the experimental period. Each structure was covered with a polyethylene film (1 mm thickness and 75% light transmittance) provided by EstufasMinho, S.A. (Fão, Portugal), while the top was kept open. The elevation of the air temperature (average +3 °C) in Temperature and Temperature + CO_2 treatments has been obtained by the greenhouse effect from OTC itself and led to an increase of 2 °C in soil temperature relative to open-filed conditions. Water flooding was maintained almost constant (5–20 cm height) in the open-field and inside the OTCs, by passing through some holes at the bottom of the polyethylene film involving the chambers.

To increase the atmospheric [CO_2] to the target level of 550 ppm in the three OTCs assigned to the treatment Temperature + CO_2, a system using continuous injection of pure industrial CO_2 was installed which fumigated CO_2 daily (24-h per day), for the two rice growing seasons. The CO_2 injection system and indoor air turbulence conditions were made as outlined by previous authors (De Costa et al., 2006). Several sensors connected to a data-logger (DL2, Delta-T Devices, Cambridge, UK) were installed at about 1 m above the soil surface to monitor the climatic parameters ([CO_2], air temperature and relative humidity) inside and outside the OTCs. To control the [CO_2] in the Temperature + CO_2 OTCs probes (model GMP222, Vaisala, Finland) were adjusted at the canopy level throughout the season. The CO_2 fumigation system operated in an on/off mode control with a continuous sampling of [CO_2] (30 s interval between samplings). When CO_2 injection was necessary, the data-logger acted over an electronic valve (7321B