Agriculture, Ecosystems and Environment 232 (2016) 17–28

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Greenhouse gas emissions as affected by different water management practices in temperate rice paddies

Matteo Peyron[a], Chiara Bertora[a,*], Simone Pelissetti[a], Daniel Said-Pullicino[a], Luisella Celi[a], Eleonora Miniotti[a,b], Marco Romani[b], Dario Sacco[a]

[a] Dept. of Agricultural, Forest and Food Sciences, University of Turin, Grugliasco, Italy
[b] Rice Research Centre, Ente Nazionale Risi, Castello d'Agogna, Italy

ARTICLE INFO

Article history:
Received 24 February 2016
Received in revised form 19 July 2016
Accepted 23 July 2016
Available online xxx

Keywords:
Methane
Nitrous oxide
Continuous flooding
Dry seeding
Intermittent irrigation
Global warming potential
Water management
Rice paddy

ABSTRACT

The mitigation of methane (CH_4) and nitrous oxide (N_2O) emissions from rice paddy fields is pivotal in minimizing the impact of rice production on global warming. The large majority of the world rice is cropped in continuously flooded paddies, where soil anaerobic conditions lead to the production and emission of significant amounts of CH_4. In this work we evaluated the effectiveness of water management techniques alternative to the conventional flooding on the mitigation of CH_4 emissions from paddy soils, and verified whether any concurrent increase in N_2O emissions can totally or partially offset their environmental benefit. Two alternative water management systems were compared to the conventional continuous flooding system (WFL): dry seeding with delayed flooding (DFL) and intermittent irrigation (DIR). Methane and N_2O emissions were monitored at field-scale over two years including both rice cropping and fallow seasons, using non-steady-state closed chamber approach. The DFL system resulted in a 59% decrease (average of the two measured years) in total CH_4 emissions with respect to WFL, while DIR annulled CH_4 emissions. The effect of CH_4 mitigation of DFL with respect to WFL was mainly concentrated within the vegetative stage, while any significant flux from DIR was recorded throughout the growing and non-growing season. However, DIR resulted in the highest emission peaks and cumulative fluxes of N_2O, almost totally occurred during the vegetative stage. In contrast, DFL and WFL showed N_2O emissions that were 77 and 93% lower with respect to DIR, respectively. Total annual fluxes suggest that the adoption of alternative water management practices that involve dry seeding and subsequent delayed flooding or intermittent irrigation can contribute to significantly reduce the global warming potential of rice cropping systems by 56 and 83%, respectively with respect to continuous flooding.

1. Introduction

Agriculture greatly contributes to anthropogenic greenhouse gas (GHG) emissions and this role is expected to remain pivotal throughout the 21st century. Annual GHG emissions from agricultural production, mainly methane (CH_4) and nitrous oxide (N_2O), were estimated at 5.0–5.8 Gt CO_2-eq y^{-1} for the 2000–2010 period (Faostat, 2013; Tubiello et al., 2013), accounting for approximately 10–12% of global anthropogenic emissions. Paddy rice cultivation is a major source of global CH_4 emissions, estimated to contribute around 11% of the overall CH_4 emissions (493–723 Mt CO_2-eq y^{-1}) in 2010 (Smith et al., 2014).

Methane fluxes from paddy fields are the net balance among the main processes of methanogenesis, (responsible for CH_4 production), methanotrophy (responsible for CH_4 consumption), and emission from soil to atmosphere (Wassmann and Aulakh, 2000). As plants develops during its growing cycle, diffusion through aerenchyma becomes the dominant process, responsible for more than 90% emitted, while ebullition and diffusion through flooded water provide minor contributions (Le Mer and Roger, 2001). Methane emissions are reported to covary with crop growth and maximum emissions peaks are normally observed in close proximity of rice panicle initiation (Gogoi et al., 2005; Pittelkow et al., 2013).

Over 75% of the world rice is produced in paddies that are continuously flooded for most of the cropping season (Van der

* Corresponding author at: Dept. of Agricultural, Forest and Food Sciences, University of Turin, Largo Paolo Braccini 2, 10095 Grugliasco, TO, Italy.
E-mail address: chiara.bertora@unito.it (C. Bertora).

http://dx.doi.org/10.1016/j.agee.2016.07.021
0167-8809/

Hoek et al., 2001). Waterlogging has several agronomic advantages: it mainly limits variations in soil moisture and temperature, and depresses soil-borne disease and weed growth. Nevertheless, flooding drastically reduces the diffusion of atmospheric O_2 into the soil, therefore promoting methanogenesis. This microbial process, in fact, requires strict anaerobiosis and low oxydo-reduction potentials, distinctive traits of flooded paddies (Le Mer and Roger, 2001).

Alternative irrigation systems limiting the presence of a permanent water layer in field have been recently introduced, primarily for water-saving purposes in areas were scarcity is a crucial issue; additionally, these techniques can also be effective at enhancing the diffusion of O_2 into the soil therefore mitigating CH_4 production (Xu et al., 2015; Yang et al., 2012; Sass and Fisher, 1997). Furthermore, since water management affects availability of methanogenic substrates, interfering with straw decomposition, any limitation in water permanence in field, especially at the beginning of the cropping season, can also indirectly reduce CH_4 emissions by containing the presence of methanogenic substrates (Watanabe et al., 1999).

However, water management practices that limit CH_4 production are generally prone to concurrently enhance N_2O emissions (Zou et al., 2005). Frequent alternations in soil redox conditions as a result of dry–wet transitions are known to substantially increase N_2O by favouring both nitrification and denitrification processes responsible for N_2O production. This circumstance can substantially offset the advantages of CH_4 mitigation achieved by introducing drainage periods (Zou et al., 2007; Wang et al., 2011).

Water management in rice cropping systems therefore plays a key role in determining the trade-off between CH_4 and N_2O emissions. The development of effective mitigation strategies aimed at minimizing the global warming potential (GWP) of rice cropping systems must therefore consider the emissions of both gases.

Only few studies have evaluated the effects of dry seeding and alternative irrigation practices (Pittelkow et al., 2014; Simmonds et al., 2015) on the overall GHG emissions from temperate paddy fields with respect to the conventional continuously flooded cultivation system.

In Europe, as in most temperate countries, two irrigation practices were introduced during the last few decades as an alternative to the conventional water management that involves water seeding and continuous flooding until ripening stage, one month before harvest (hereafter identified as WFL). The first alternative consists of dry seeding and delayed flooding at tillering about one month after seeding (hereafter termed DFL), while the second is based on dry seeding followed by intermittent irrigation (henceforth called DIR).

In 2014, the DFL cropping system involved 72,984 ha accounting for about 33% of the total area cultivated to rice in Italy (219,532 ha). Although the application of this system does not lead to a reduction in water use (Zhao et al., 2015), the delay in flooding can effectively limit the accumulation of phytotoxic substances (like phenolic acids, phenolic aldehydes and low molecular weight aliphatic acids) derived from straw fermentation, and reduce inhibition on plant growth (Pramaink et al., 2001).

The DIR cropping system has a rather limited relevance in Italy; it is highly functional in very permeable soils where scarce water availability does not provide for continuous flooding or in areas in proximity of inhabited areas as a mosquito control strategy (Mutero et al., 2000; Klinkenberg et al., 2003).

Building upon these considerations, we hypothesized that, with respect to continuously flooded systems, alternative water management practices that reduce the permanence of ponding water in temperate rice paddies may contribute to reduce CH_4 emissions, though this environmental benefit may be partially offset by a concurrent increase in N_2O emissions. We tested this hypothesis at field-scale by evaluating variations in the annual emissions of CH_4 and N_2O and their specific contribution to the GWP of three water management practices (WFL, DFL, DIR) over a two year experimental periods.

2. Materials and methods

2.1. Experimental site description

A two-year field experiment was conducted in 2012–2013 at the Italian Rice Research Centre (Ente Nazionale Risi) in Castello d'Agogna, near Pavia. The site is located in the western area of the plain of the river Po (NW Italy) within the Italian rice district. The soil of the experimental field was a Fluvaquentic Epiaquept coarse silty, mixed, mesic (Soil Survey Staff, 2014) having a loam topsoil (0–30 cm) and a silty loam plough pan (30–40 cm). The topsoil had a mean pH (H_2O) of 5.9, 9.5 g kg^{-1} organic C, 0.8 g kg-1 total N, and a cation exchange capacity of 10.2 cmol(+) kg^{-1}. Further details of the site's soil were provided elsewhere (Said-Pullicino et al., 2016).

The climate is temperate subcontinental, with a mean annual temperature of 12.7 °C and a mean annual precipitation of 704 mm (average of last 20 years), characterized by two main rainfall periods in spring (April–May) and autumn (September–November). In 2012 and 2013, mean annual air temperature was 13.0 °C, while during the growing season the mean temperature was 22.7 °C (Fig. 1). The annual cumulative rainfall over the experimental period was 623 and 756 mm in 2012 and 2013, respectively, with around 70% occurring during intercropping periods between

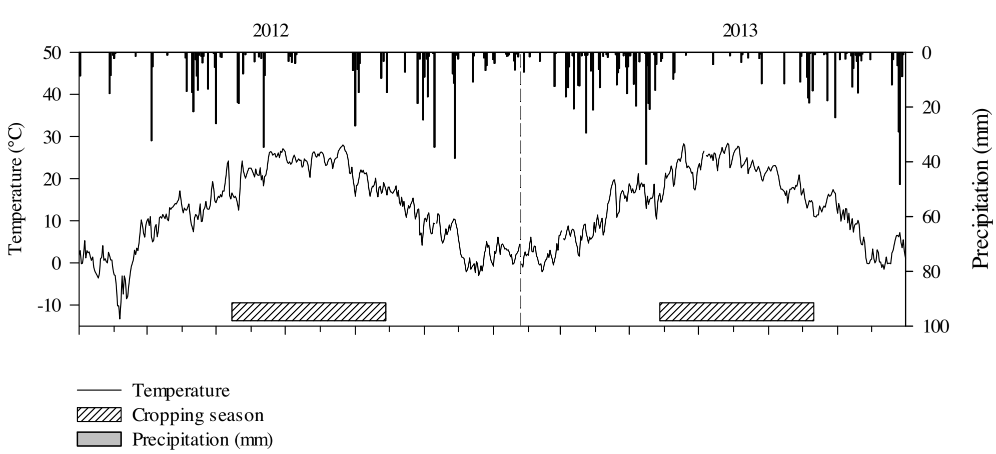

Fig. 1. Seasonal variations in precipitation and temperature during the experimental period. Precipitations refer to three days accumulation.